ESKİŞEHİR OSMANGAZİ UNIVERSITY

PHYSICS II
EXPERIMENTS LABORATORY BOOK FOR ENGINEERING STUDENTS

AUTHORS

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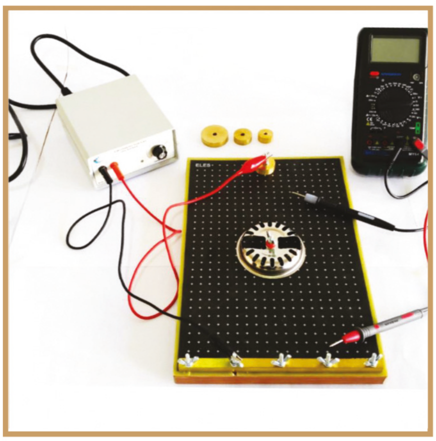

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PHOTO

Experiment Code	Experiment Name	Date	Teaching Staff Signature
E1	Electrolysis		
E2	Ohm's Law		
E3	Wheatstone Bridge		
E4	Electrostatics and Coulomb's Law		
E5	Equipotential and Electric Field Lines		
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PREFACE

This book was prepared for freshman students of Eskişehir Osmangazi University, Engineering and Architecture Faculty departments to use during spring semester Physics II Laboratory course. Main goal of this course is to teach electricity and magnetism by observations in a laboratory environment. In this respect, it complements problem solving skills obtained theoretically from Physics II classroom lectures and books.

Electromagnetism is one of the fundamental interactions in nature and its origin lies in a property possessed by matter. Electromagnetic interaction has a precise theory that also governs light and other forms of electromagnetic radiation. Electricity and magnetism can be observed in many natural phenomena. Furthermore, we come across applications of electromagnetism in almost all of the technological products in our daily life.

Dear students, Physics II Experiments Laboratory Book, aiming to provide a better understanding of natural phenomena and working principles of technological products, contains ten experiments. The data analysis, commenting and reporting on your experimental results, the pre- and post-lab questions for each experiment will enable you to grasp the experiment better. General information for Physics II Laboratory operation and laboratory safety are given in detail under the title of “Physics Laboratory Working Instructions”.

Upon completing the fall semester courses of Physics I and Physics I Laboratory, we believe that students who take Physics II and Physics II Laboratory courses will better develop a scientific understanding when proceeding in their own disciplines. In this regard, some new experimental sets are brought in Physics II Laboratory in the past year. Both additional new experiments and also the desire to improve the text for the present experiments brought out the need to prepare a new laboratory book. In preparation of this laboratory book, we drew upon the laboratory manuals that were used in earlier years. Therefore, we thank our colleagues who contributed to these manuals.

Finally, be aware that this laboratory book is still under development. We invite both our colleagues and students to make corrections, comments, and suggestions. It is very precious to get feedback from you that will contribute in our efforts to make this book more useful and clear.

We thank to Physics II Experiments Laboratory Book Author Team for their support and contributions, Physics Laboratory Supervisor Halil Yasin Adıyaman for his help in the set-up and maintaining of the experiments, and master's student Ali Olkun for his help in drawing figures.

January, 2017

Prof. Dr. Emel ALĞIN
Asst. Prof. Dr. Derya PEKER
On Behalf of Physics II Experiments Laboratory Book Author Team

PHYSICS LABORATORY
WORKING INSTRUCTIONS

1. Students should come to the lab on time. **Students who arrive later than 15 minutes are not allowed to enter the laboratory.**
2. Experimental groups and loop scheme are announced on the laboratory board. **Students cannot change their groups arbitrarily.**
3. **Students should obey laboratory staff's cautions.** Laboratory staff have the authority to make any changes to keep the course layout.
4. **Avoid disrupting the course by walking around the tables or making noise in the lab.**
5. **Keep your cell phones switched off during the course.** It is not enough that your phone is on silent mode.
6. Students should bring their necessary tools with themselves, **such as pen, pencil, pencil leads, eraser, ruler, calculator, etc.**
7. Before coming to the laboratory, students should be prepared for the theory and experimental procedure using **Physics Laboratory Book.**
8. **Students should also be prepared for pre- and post-oral examination by laboratory staff.**
9. Before the experiment, students should check experimental equipment and **inform laboratory staff for any damage and loss.** In the case of any experimental damage, responsibility belongs to the members of the relevant experiment.
10. **Students should not set or start the experiment before staff's approval.**
11. Passing grade for Physics Laboratory course is determined from 50% contribution of **"experimental grade"** and 50% contribution of **"final examination grade"**. Students who succeed all of the experiments have the right to take **the final examination.**
12. The students who take the laboratory course prepares a report for every experiment they perform. "The experimental grade" will be calculated by taking the average of these report scores.
13. Report grading consists of the use of experimental instruments, your performance, discussion of the experiment, and how tidy you leave your experimental equipment. Detailed grading is done with report layout, results, graph drawing, evaluation, and success during the experiment.

14. “Laboratory final examination grade” is the final test grade from which the student take in the final week.

15. There will not be any laboratory course during the midterm weeks.

16. At the end of each experiment, when submitting in your report, do not forget to get your report signed, to get the approval page (with your photo) signed, and to sign the attendance list. Note that you cannot claim any right for your reports that you threw under the staff’s door without an approval signature.

17. The case of student’s nonattendance to more than 3 (three) experiments results in failure of the course as an absence. Students are allowed to make up their one or two experiments during the make-up week if they are excused absent with a medical report or official permission. The grades for uncompleted experiment(s) will be considered as **0 (zero).**

18. Make-up week and students will be announced on the announcement board after the completion of the experiments.

19. At the end of each experiment, students should leave experimental equipment and their table clean and tidy.

20. You can obtain Physics Laboratory Book from the Eskişehir Osmangazi University social facilities economic management bookstore.

GOOD LUCK…

CONTENTS

ELECTROLYSIS

E1

ELECTROLYSIS

E1

PURPOSE OF THE EXPERIMENT:

1. To understand the principle of electrolysis.
2. To investigate electrolysis process in copper coating on a metal.

EQUIPMENT FOR THE EXPERIMENT:

Copper electrodes

Electrolysis cup

Copper sulfate ($CuSO_4$) solution

DC power supply

Rheostat

Ammeter (on DC power supply)

Connection cables

Chronometer

Precision scale

THEORY:

Electrolysis is a technique that uses a direct electric current (DC) through an ion-containing solution and produces chemical changes at the electrodes. Electrolysis is used extensively in metallurgical processes, such as in extraction (electrowinning) or purification (electrorefining) of metals from ores or compounds.

Let's investigate the principle of electrolysis with an example. Whenever copper sulfate ($CuSO_4$) is added to water, it gets dissolved in the water. As the $CuSO_4$ is an electrolyte, it splits into Cu^{++} (cation) and SO_4^{--} (anion) ions and move freely in the solution.

Electrolysis uses an electrical current to move ions in an electrolyte solution between two electrodes. In copper electrolysis, if two copper electrodes are immersed in $CuSO_4$ solution and a current is applied by a battery, Cu^{++} ions (cation) leave the anode (positive electrode) and move toward the cathode (negative electrode). On reaching on the cathode, each Cu^{++} ion will take electrons from it and becomes neutral copper atoms. Similarly, SO_4^{--} (anion) ions will move towards anode (positive electrode) where they give up two electrons and become SO_4 radical but since SO_4 radical cannot exist in the electrical neutral state, it will attack copper anode and will form copper sulfate. However, in water $CuSO_4$ cannot exist as single molecules instead of that, $CuSO_4$ will split into Cu^{++} and SO_4^{--} and dissolve in water. So during electrolysis of copper sulfate with copper electrodes, copper is deposited on cathode (i.e., copper coating) and same amount of copper is removed from anode.

There are $N_A = 6.02\times10^{23}$ atoms (i.e., Avagadro's number) in one mole of a given substance. Therefore, the amount of charge *q* necessary in order for a monovalent ion to turn into a neutral atom is

$$q = 1.60\times10^{-19}\times6.02\times10^{23} = 96540\ \text{C}. \tag{1.1}$$

When 96540 coulombs of electric charge is passed through an electrolyte composed of a substance with atomic mass *A* and valency *n*, a mass of A/n gram is deposited at the cathode. If a total electric charge of Q is passed for a given time *t*, then the amount of mass deposited at the cathode is given by

$$m = \frac{Q}{96540}\frac{A}{n}\cdot \tag{1.2}$$

Here $Q = It$, where *I* is the current that passes for a given time of *t* and is defined as

$$I = m\frac{96540}{t}\frac{n}{A}\cdot \tag{1.3}$$

If the cations have valency of two like Cu^{++} then for every cation, there would be two electrons transferred from cathode to cation. If mass of the deposited copper *m* is known, then the current passed through the circuit can be determined from

$$I = m\frac{96540}{t}\frac{2}{63.5} \tag{1.4}$$

where the atomic mass of copper is 63.5 g/mol.

PROCEDURE:

1. Rub the electrodes with sandpaper to remove any deposits of the earlier experiment. Then wash and dry them before you use.
2. Weigh each electrode carefully and record their masses m_1 and m_2 in Table 1.1.
3. Set up the circuit shown in Figure 1.1. Do not switch on the circuit before checked out by laboratory attendant.

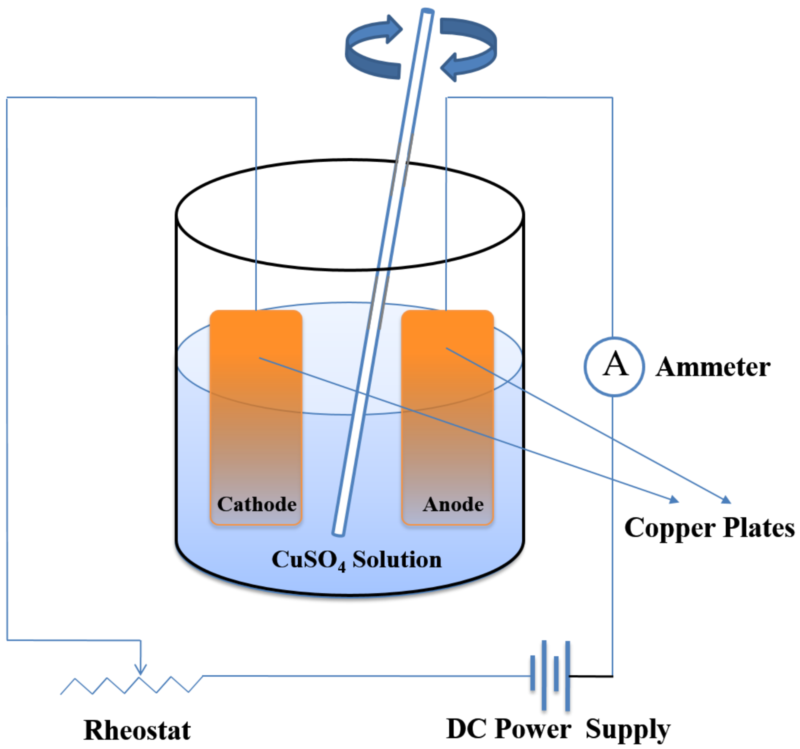


Figure 1.1. Setup for electrolysis experiment.

4. Start the chronometer just at the time you switch on the circuit. Adjust the current such that the ammeter does not exceed 1 A. Record this value I_1 in Table 1.1. Try to keep this current value constant by using a rheostat (Do not adjust it with power supply).
5. Stir the solution continuously for homogeneity, yet do not touch the electrodes. Turn off the power supply at the end of the time (t) you are told by the laboratory attendant. Record this time t in Table 1.1.
6. Remove the electrodes from the solution carefully. Do not wipe them off, but dry them with a drier machine. Reweigh each electrode sensitively, and record their masses m_1' and m_2' in Table 1.1. Determine the heavier and lighter electrodes. You should find an increase in mass of cathode (copper deposited) and a loss in mass of anode.

7. Find the increase and decrease in masses Δm_1 and Δm_2 and record them in Table 1.1. Calculate the amount of transferred mass by using $m = \frac{\Delta m_1 + \Delta m_2}{2}$ and record it in Table 1.1.

8. Calculate the current I_2 that passes through the solution using

$$I = m \frac{96540}{t} \frac{2}{63.5}$$

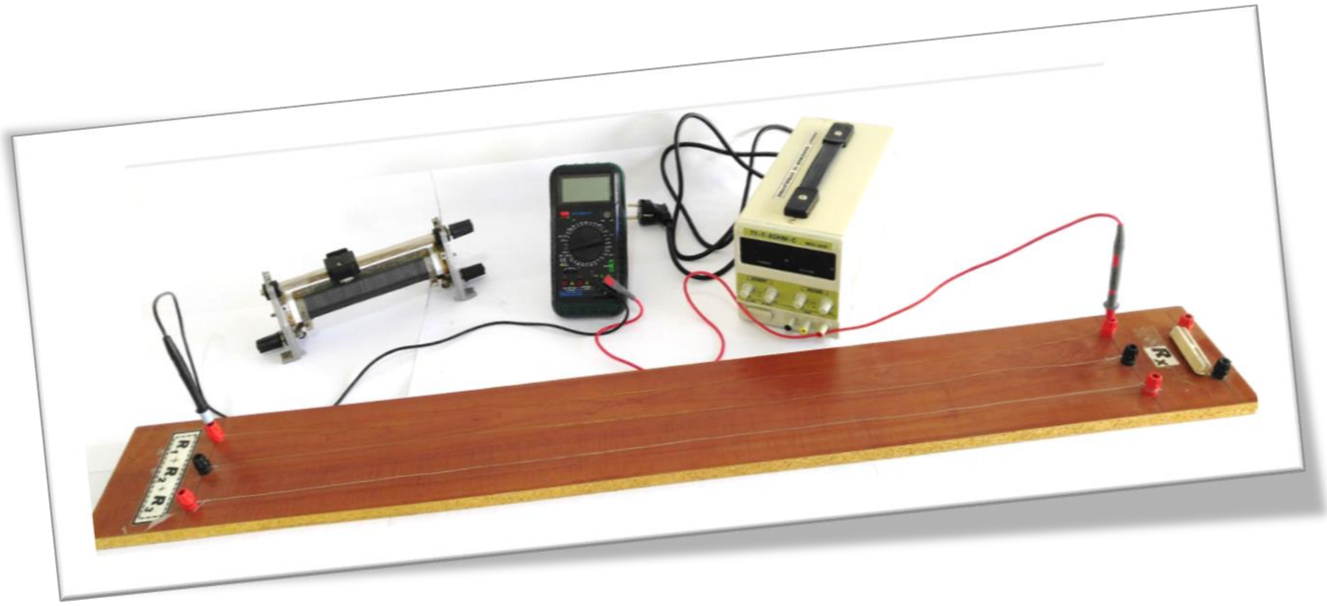
and record it in Table 1.1.

9. Calculate the difference between the current you read in ammeter I_1 during the experiment and the current you calculated I_2 Record the difference $(|I_1 - I_2|)$ in Table 1.1. Make comments on this difference.

EXPERIMENTAL DATA:

TABLE 1.1										
I_1 (A)	t (s)	m_1 (g)	m_2 (g)	m_1' (g)	m_2' (g)	Δm_1 (g)	Δm_2 (g)	m (g)	I_2 (A)	$\lvert I_1 - I_2 \rvert$ (A)

OHM'S LAW



E2

OHM'S LAW

E2

PURPOSE OF THE EXPERIMENT:

To measure resistance using an ammeter and a voltmeter.

EQUIPMENT FOR THE EXPERIMENT:

Three 1-m long conductor wires with different thicknesses

An unknown resistance (R_x)

Multimeter (for use as a voltmeter)

DC power supply

Ammeter (on DC power supply)

Rheostat

Connection cables

THEORY:

Electricity is indispensable in our daily life. Tools used in our homes such as television, computer, refrigerator have electrical circuits inside and are all electrically operated. Therefore, Ohm's Law is a widely used law with its simplicity and usability in the field of electrical science and electronical engineering. When Ohm's law is applied to an electrical circuit; it gives the relationship between current, potential difference, and resistance.

Free electrons in a piece of metal move randomly. Due to this randomness, there is no electric current through the metal. If a metal wire with a length of L is connected to the poles of a battery with the potential difference V between its terminals, an electric field $\vec{E}$ occurs through the metal wire and its magnitude is given by:

$$E = \frac{V}{L}. \tag{2.1}$$

This electric field is directed from the positive pole to the negative pole along the wire and exerts force on free electrons in the wire. These electrons then move in the opposite direction of the electric field. Thus, an electric current is formed through the wire. The magnitude of the resulting electrical current depends on the magnitude of the applied electric field. Thus, the amount of free electrons passing through a unit time from any perpendicular section of a conductor wire is called as the electric current. If the amount of the charge passing a perpendicular section of the conducting wire in a time interval t is q, then the electric current i is given by

$$i = \frac{q}{t}. \tag{2.2}$$

Since the unit of charge is coulomb (C) and time is measured in seconds (s) in SI unit system, the unit of electric current is C/s. The unit C/s has also a special name called ampere (A). In order for the electric current to flow from a circuit, the circuit must be a closed circuit. If the circuit is switched on, free electrons cannot pass through the air. So no electric current can flow. As seen in Figure 2.1, the current passing through a conductor wire is measured with an ammeter. The ammeter is connected in series on the arm to measure the current.

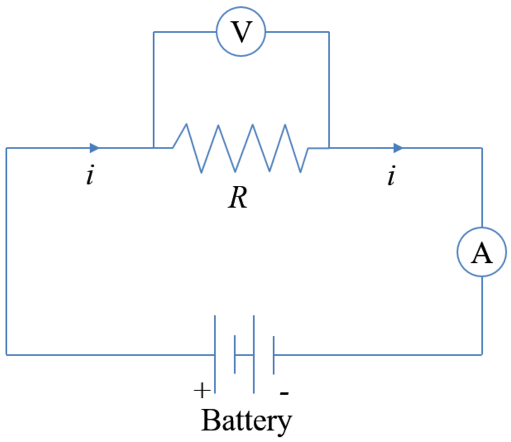


Figure 2.1. A closed circuit with current, potential difference, and resistance.

The potential difference applied to an electric circuit is a scalar quantity. In SI system, the unit of the potential difference between two points is called volt (V) in honor of Alessandro Volta (1745-1827) who developed the first battery. As seen in Figure 2.1, the potential difference between the two ends of a circuit is measured by a voltmeter. The voltmeter is connected parallel to the points where the potential difference is to be measured.

If a potential difference V is applied between the ends of a conductor, an electric field $\vec{E}$ is created within it and thus a current i flows through the wire. While temperature is held constant, if we change the potential difference V between the ends of the conductor, then the electric current passing through the wire will change. However, the ratio of the current i to the potential difference V will remain constant, i.e. V/i = constant. This ratio is called as resistance and is indicated as R. Usually, the resistance of a conductive wire R is given by

$$R = \frac{V}{i} = \text{constant} \tag{2.3}$$

which is known as "Ohm's Law" since it was first discovered by the German Scientist George Simon Ohm (1787-1854) in 1827. Ohm's Law is the most basic law of electricity and defines the mathematical relationship between current, potential difference, and resistance (see Figure 2.1). This law can also be applied to electrical circuits carrying alternating current. In SI system, the unit of resistance is volt/ampere (V/A). This is also known as ohm (Ω). Resistance in electric circuits is indicated by a  sign. Resistance of a wire depends on the material of which the wire is made, the length of the wire, and the cross sectional area of the wire. Resistors in circuits are used for different purposes, i.e., to keep the current at a steady value, to divide and reduce the supply voltage for the other elements to operate, to prevent any damage of sensitive circuit elements from high currents, to make the load (receiver) task and to produce heat energy. The resistance of most circuit elements is typically between 10 Ω and 100.000 Ω.

As shown in Eq. 2.3, the current passing through a conductor is directly proportional to the potential difference V between the two ends of the wire and is inversely proportional to the resistance R. Accordingly, the potential difference between the ends of the conductor can be plotted as a function of the current passing through the conductor. In Figure 2.2 shows the variation of potential difference V with current i. The slope of the graph, which is a straight line, will then give us the resistance R of the conductor. Furthermore, Eq. 2.3 shows that resistance is always positive.

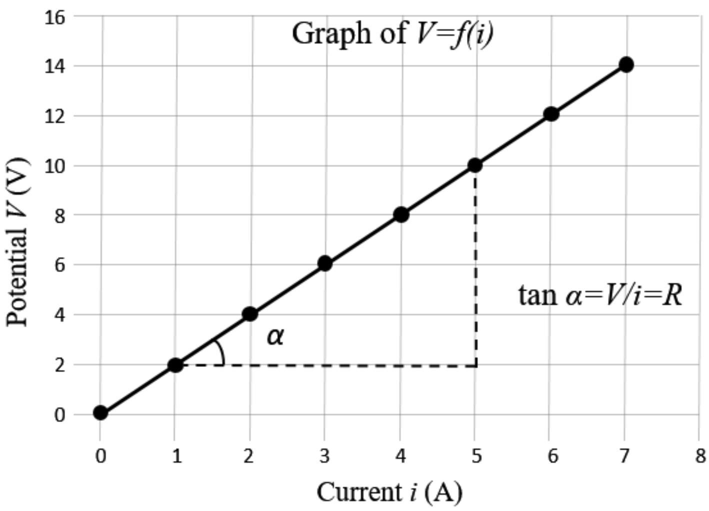


Figure 2.2. Variation of potential difference V with current i.

PROCEDURE:

1. Construct the circuit shown in Figure 2.3 for the first conductor wire (R_1 resistance).

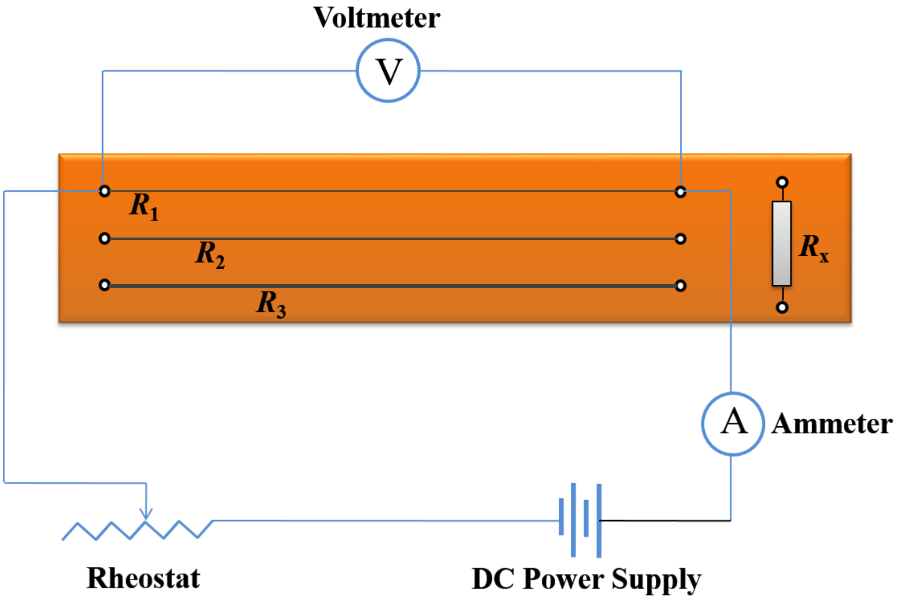


Figure 2.3. The first setup for Ohm's Law experiment.

2. For the first conductor wire, measure five different potential (V) and current (i) values by adjusting the rheostat and record these values in Table 2.1. Use your data and the relation $V = iR$ to find five resistance values and record them in Table 2.1. Then take the average of these resistances and record it as R_{1avg} in Table 2.2.

3. Repeat steps 1 and 2 for the second and third conductor wires (R_2 and R_3 resistances) and record your results as R_{2avg} and R_{3avg} in Table 2.2.

4. After completing these steps, disconnect the first circuit and construct the second circuit shown in Figure 2.4.

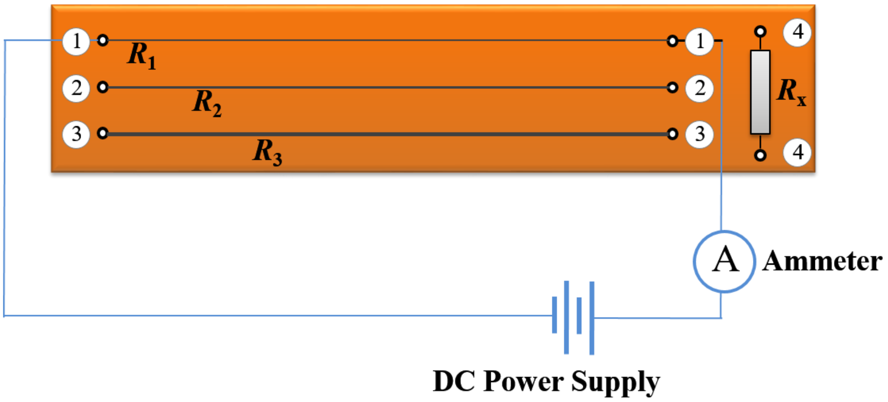


Figure 2.4. The second circuit for Ohm's Law experiment and connection order of the resistors.

5. **5.** Set the power supply voltage to a fixed value and use ammeter to measure the currents as i_1, i_2, and i_3 for three resistors R_1, R_2, and R_3, respectively. Record the currents in Table 2.2.

6. Now, connect an unknown resistance R_x to the same circuit and use ammeter to read the current value i_x and record this current in Table 2.2.

7. Use your data in Table 2.2 to draw the graph of $i = f(R)$.

8. By using the graph, determine the unknown resistance R_x that corresponds to the current i_x (see Figure 2.5).

9. Measure the resistance R_x with an ohmmeter and record it in Table 2.3. Compare these two resistance values and interpret on them.

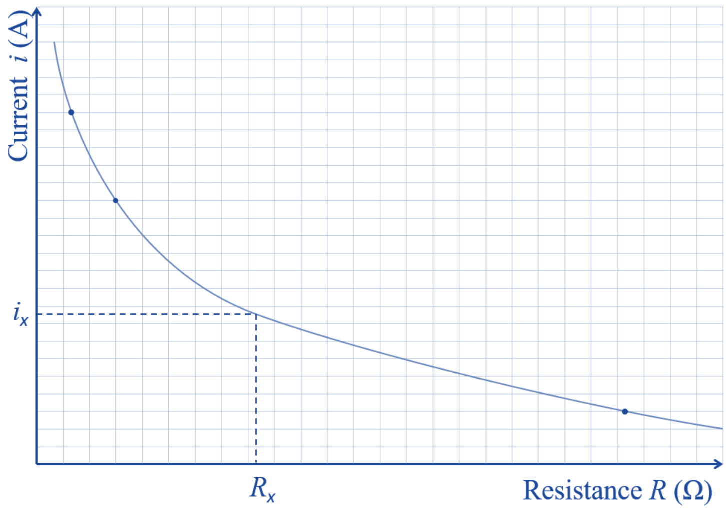


Figure 2.5. Finding the unknown resistance R_x from the graph.

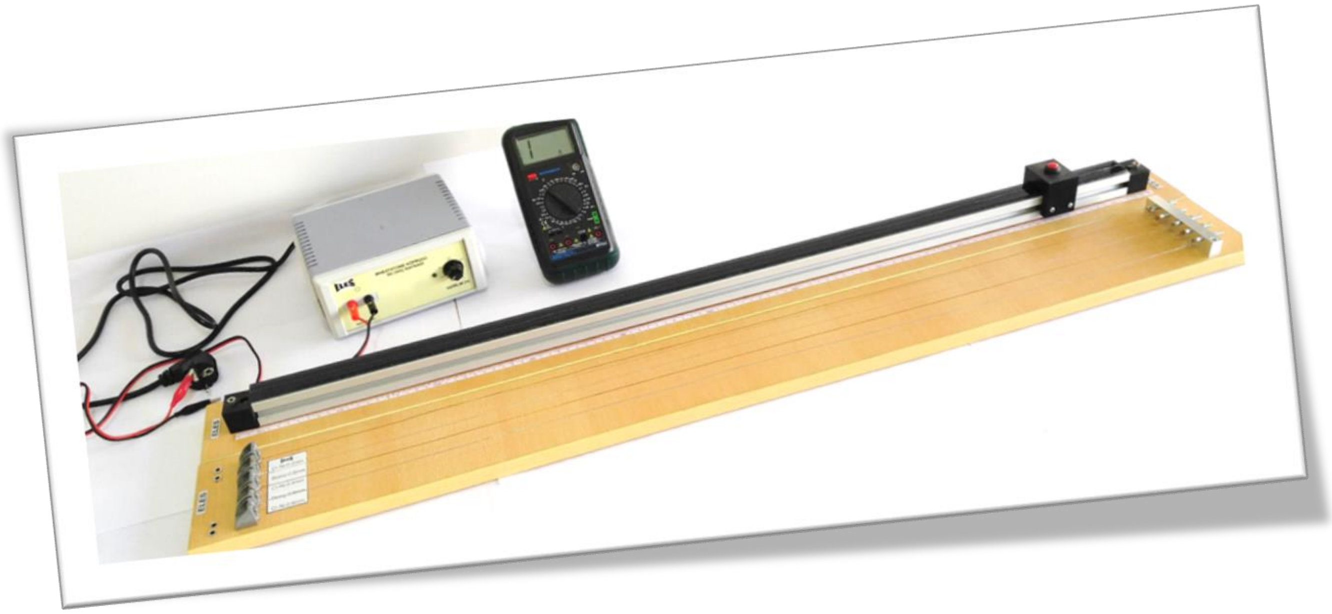
EXPERIMENTAL DATA:

TABLE 2.1						
		1. Measure	2. Measure	3. Measure	4. Measure	5. Measure
1. Conductor Wire	V (V)					
	i (A)					
	R_1 (Ω)					
2. Conductor Wire	V (V)					
	i (A)					
	R_2 (Ω)					
3. Conductor Wire	V (V)					
	i (A)					
	R_3 (Ω)					

TABLE 2.2			
R_{1avg} (Ω)		i_1 (A)	
R_{2avg} (Ω)		i_2 (A)	
R_{3avg} (Ω)		i_3 (A)	
		i_x (A)	

	TABLE 2.3	
	Value From the Graph	Value Using Ohmmeter
R_x (Ω)		

WHEATSTONE BRIDGE



E3

WHEATSTONE BRIDGE E3

PURPOSE OF THE EXPERIMENT:

1. To understand the working principle of Wheatstone bridge.
2. To find the value of an unknown resistance by using Wheatstone bridge assembly.
3. To calculate the resistivity of a wire.

EQUIPMENT FOR THE EXPERIMENT:

Wheatstone bridge resistance table

DC power supply

Resistor set (0.40 Ω and 47 Ω)

Multimeter

Connection cables

Cr-Ni wires (95 cm in length and 0.20, 0.40, and 0.60 mm in diameter)

Brass wire (95 cm in length and 0.60 mm in diameter)

Bronze wire (95 cm in length and 0.60 mm in diameter).

THEORY:

Wheatstone bridge is an assembly to find an unknown resistance easily with high precision by using three known resistances. Therefore, it is often used in resistance testers where high precision measurement is necessary.

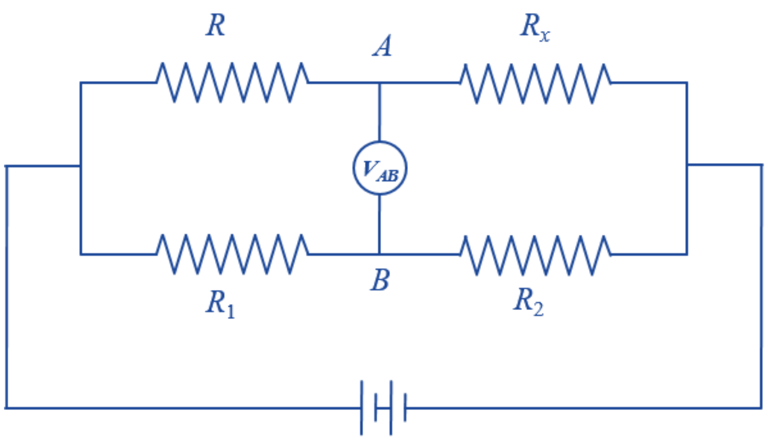


Figure 3.1. Wheatstone bridge circuit diagram.

As seen in Figure 3.1, Wheatstone bridge circuit consists of two simple series-parallel resistance arrangements connected between voltage supply terminals. We can understand this circuit by examining some simpler circuits. Consider a series circuit shown in Figure 3.2.

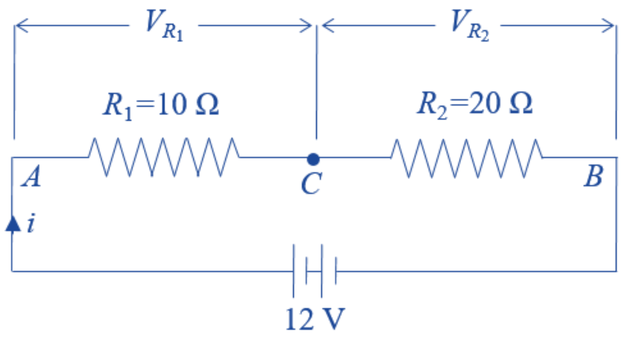


Figure 3.2. Resistors connected in series.

As the two resistors are in series, the same current *i* flows through each of them. Therefore, the current flowing through these two resistors is given as:

$$i = \frac{V}{R_T} \tag{3.1}$$

$$i = \frac{V}{R_T} = \frac{12\ \text{V}}{10\ \Omega + 20\ \Omega} = 0.40\ \text{A}. \tag{3.2}$$

The voltage at point C, which is also the voltage drop across the 20-**Ω** resistor, is calculated as:

$$V_{R_2} = i \times R_2 = 0.40\ \text{A} \times 20\ \Omega = 8.0\ \text{V}. \tag{3.3}$$

Here, we can see that the source voltage is shared among the two series resistors in direct proportion with their resistances 4 V and 8 V, respectively. Now let's connect two identical series-connected circuits in parallel.

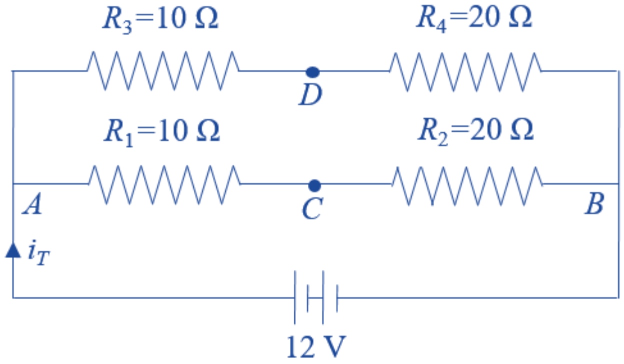


Figure 3.3. Parallel and series connected resistors.

As the second series circuit has the same resistive values as the first circuit, point C and point D will have the same voltage drop. Since both points are at the same voltage, i.e., $V_C = V_D = 8.0\ \text{V}$, the voltage difference between C and D will be zero, and the bridge network is said to be in balance.

If the resistors R_3 and R_4 are reversed ($R_3 = 20\ \Omega$ and $R_3 = 10\ \Omega$), the voltage drop at point D will be:

$$V_{R_4} = 0.4\ \text{A} \times 10\ \Omega = 4.0\ \text{V}. \tag{3.4}$$

In this case, the potential difference between C and D will be $8.0 - 4.0 = 4.0\ \text{V}.$ When this happens the parallel network becomes unbalanced.

Then we can see that the resistance ratio between these two parallel arms, ACB and ADB, results in a voltage difference between 0 volts (balanced) and the maximum supply voltage (unbalanced), and this is the basic principle of the Wheatstone bridge circuit.

From the above consideration, the balance condition, i.e., zero potential difference, can be obtained if the resistance ratio is as follows

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}. \tag{3.5}$$

The assembly used in this experiment (see Figure 3.4) consists of a known resistance R and a uniform resistance wire fixed on a ruler. One end of the slider is connected to the voltmeter and the slider can move along the wire. Sliding contact point separates the wire into two parts (L_1 and L_2). The slider can be brought to a point on the wire such that the voltmeter shows zero potential which means that there is an equal potential between the two ends of voltmeter. This property of Wheatstone bridge lets us write the following equation;

$$R_x = \frac{R_2}{R_1} R. \tag{3.6}$$

On the other hand, the relationship between the resistance and the resistivity is given by

$$\rho = \frac{R\,S}{L} \tag{3.7}$$

where S is the cross sectional area of the wire $(S = \pi r^2)$. Resistances R_1 and R_2 are identical, therefore;

$$\frac{R_2}{R_1} = \frac{\rho L_2 / S}{\rho L_1 / S} = \frac{L_2}{L_1}. \tag{3.8}$$

By substituting Eq. 3.8 in Eq. 3.6, we obtain the unknown resistance as follows:

$$R_x = \frac{L_2}{L_1} R. \tag{3.9}$$

Therefore, by using a known resistance R and by measuring the lengths (L_1 and L_2), an unknown resistance R_x can be determined.

PROCEDURE:

1. Set up the circuit shown in Figure 3.4 by using the resistance $R = 47\ \Omega$ for Cr-Ni wires, and resistance $R = 0.40\ \Omega$ for brass and bronze wires.

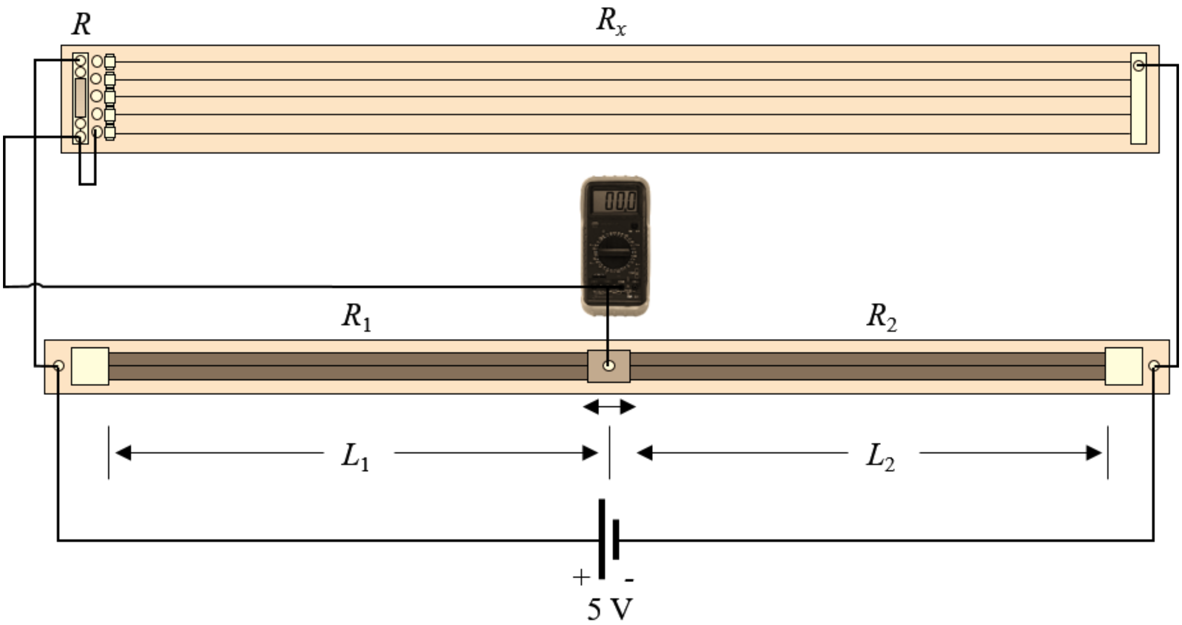


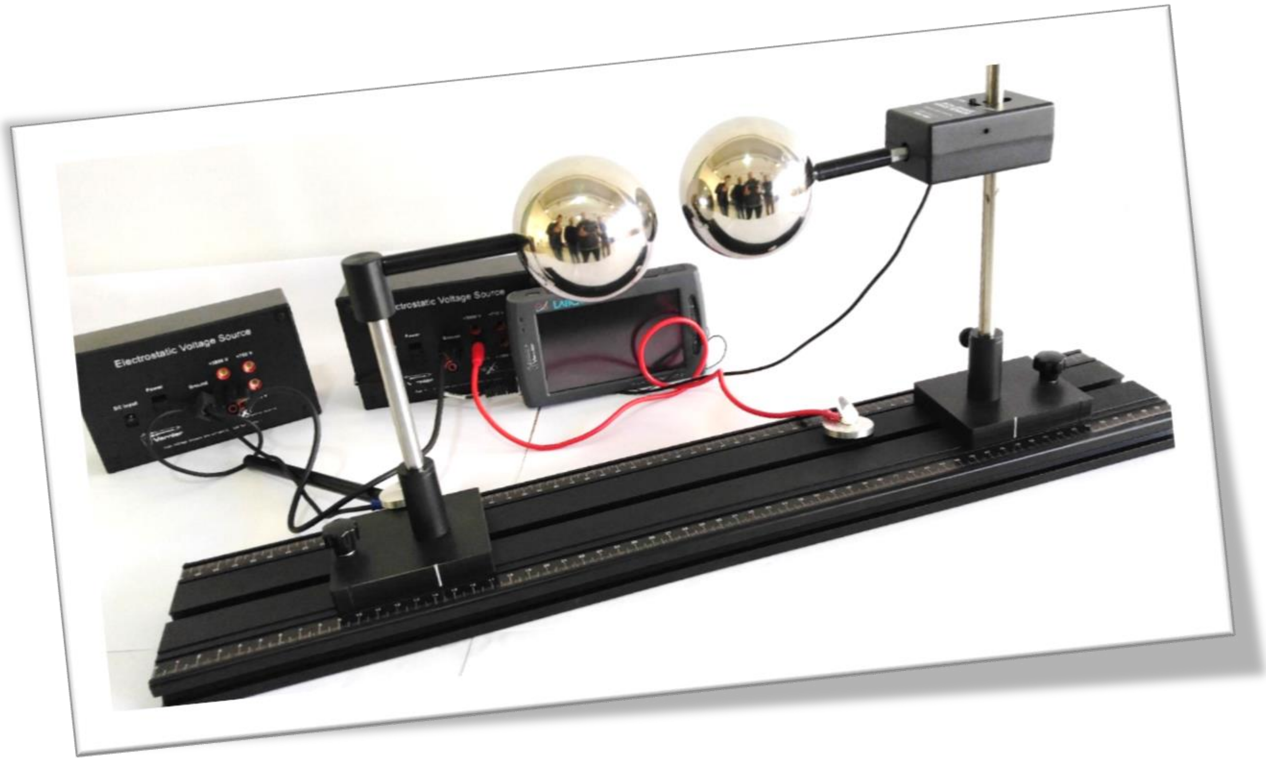
Figure 3.4. Experimental setup for Wheatstone bridge.

2. Adjust the multimeter as DC voltmeter and set the power supply to 5.0 V.
3. Find the position of the slider at which the voltage value V_{AB} read from multimeter is zero. Make sure that the voltmeter is at the most precise measurement position, i.e., 200 mV.
4. Measure the lengths L_1 and L_2 with a ruler, and record them in Table 3.1.
5. Repeat step 4 for five times and record L_1 and L_2 values in Table 3.1. For each measurement, use Eq. 3.9 to find the values of R_x and record them in Table 3.1. The value R in this equation is the value of the known resistance that you use.
6. Calculate the resistivity of each resistance wire by using the resistance values and Eq. 3.7. Take the length of each wire as $L = 95\ \text{cm}$. Calculate the average resistivity for three Cr-Ni wires.
7. Plot the graph $R = f\left(1/r^2\right)$ on a graph paper by using three resistance values R_x that you obtained for the Cr-Ni wires of different thicknesses and the wire radii. Calculate the slope of the graph and use Eq. 3.7 to find the average resistivity.
8. Compare the average resistivity values that you found in the last two steps, and comment on your result.

EXPERIMENTAL DATA:

TABLE 3.1								
Wire Type	Wire Diameter d (mm)	L_1 (cm)	L_2 (cm)	R_x (Ω)	Cross Section S (cm^2)	ρ (Ωcm)	P_{avg} (Ωcm)	ρ_{graph} (Ωcm)
Cr-Ni	0.20							
Cr-Ni	0.40							
Cr-Ni	0.60							
Bronze	0.60							
Brass	0.60							

ELECTROSTATICS and COULOMB'S LAW



E4

ELECTROSTATICS and COULOMB'S LAW

E4

PURPOSE OF THE EXPERIMENT:

1. To measure total amount of static charge on a uniformly-charged conducting sphere.
2. To calculate maximum amount of charge on surfaces at certain potentials.
3. To investigate electric force between two uniformly-charged conducting spheres as a function of the distance between them.
4. To compare experimental results with Coulomb's Law.
5. To calculate the permittivity of free space.

EQUIPMENT FOR THE EXPERIMENT:

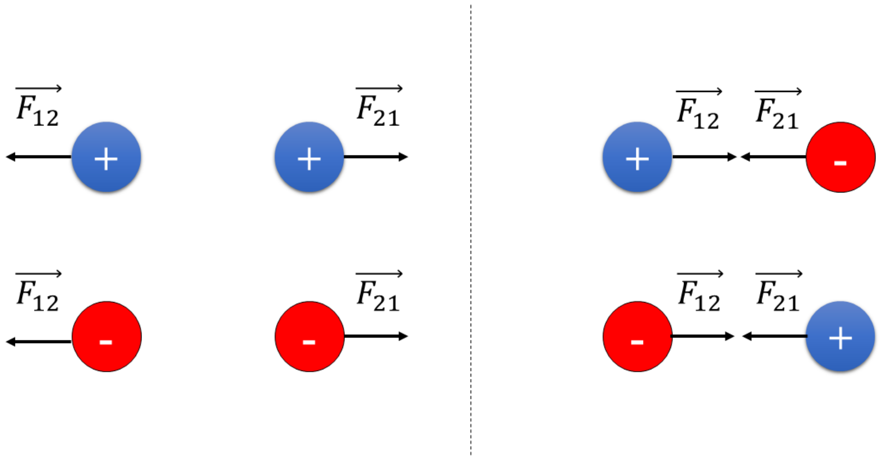
Electrostatic voltage supplies
Identical conducting spheres
Optical rail
LabQuest – 2 measurement devices
Force sensor
Charge probe
Discharge Probe
Charge measurement probe
Connection wires

THEORY:

4.1. ELECTROSTATICS

Interacting charged bodies exert electrical force on each other. Electrostatics deals with interaction forces between stationary or slowly-moving electric charges and their equilibrium conditions.

Electrical charge must be in two different forms to provide attractive and repulsive ability of electrical force. These are positive (+) and negative (–) charges. Attractive and repulsive forces between two point charges are shown in Figure 4.1.



(a) **(b)**

Figure 4.1. Forces between **(a)** two point charges of the same sign and **(b)** two point charges of different sign.

Protons (p^+) in atomic nucleus have positive charges and electrons (e^-) in atomic orbitals have negative charges. The charge of an electron is an elementary charge. The value of the elementary charge is 1.6×10^{-19} coulombs (C). As the electric charge is quantized, the charge of any object is always an integer multiple of the elementary charge. The electric charge is also conserved.

4.2. COULOMB'S LAW

It is difficult to make quantitative experiments with electrical charge, because charge carriers tend to rearrange themselves in the presence of other charged bodies. In the 18th century, an experiment performed by Joseph Priestley showed that when he charged a hollow sphere, he observed that there was no force exerted on a charge placed inside the hollow sphere. Similar to the gravitational force introduced by Newton, Priestley claimed that the electrical force decreases as $1/r^2$:

$$F \propto \frac{1}{r^2}. \tag{4.1}$$

In 1785, Charles Coulomb measured electrical forces between two charged spheres by changing the distances between them. Hence, he proved that the electrical force decreases with $1/r^2$ as suggested by Priestley. Then, Coulomb invented a method to vary the amount of charge in a sphere systematically. When a charged metal sphere is brought in contact with an identical metal sphere of no charge, both spheres have the same final charge of $q/2$. Both spheres exert force of equal magnitude on a third charged sphere. This experimental method is shown in Figure 4.2.

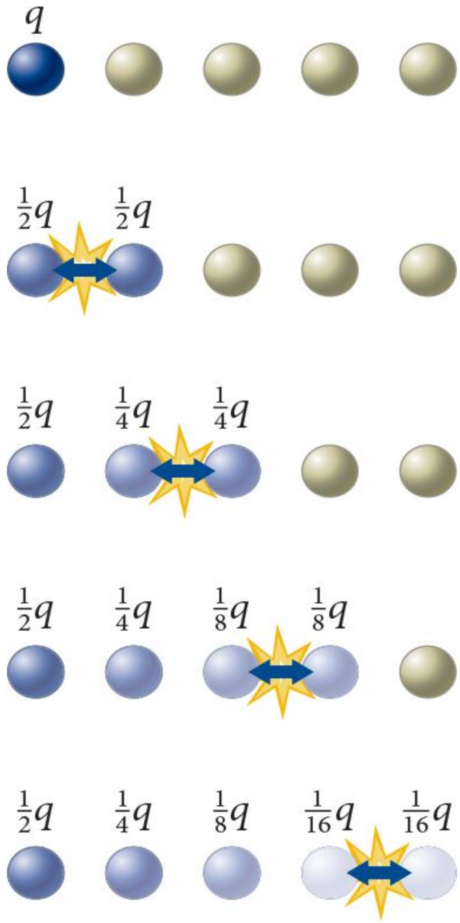


Figure 4.2. Charge sharing of spheres that are successively allowed to be in contact with each other.

Accordingly, Coulomb concluded that the magnitude of force between two electric charges is proportional to the product of their charges and it is inversely proportional to the distance between them. This is called Coulomb's Law and it is valid for point charges. Then the magnitude of electrical force between two point charges q_1 and q_2 with a distance r between them is given as follows;

$$F = k\frac{q_1 q_2}{r^2}. \tag{4.2}$$

This force is also referred as electrostatic force. This is due to the stationary distribution of the charges. The constant k is called as "**Coulomb constant**" and its value is given as

$$k = 8.99\times 10^9 \approx 9\times 10^9 \ \mathrm{Nm^2/C^2}. \tag{4.3}$$

It can also be written in terms of the permittivity of free space ε_0;

$$k = \frac{1}{4\pi\varepsilon_0} \tag{4.4}$$

$$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/Nm^2}\ . \tag{4.5}$$

4.3. POTENTIAL OF A CONDUCTING SPHERE

A capacitor that consists of two concentric conducting spheres of outer radius r_a and inner radius r_b is shown in Figure 4.3.

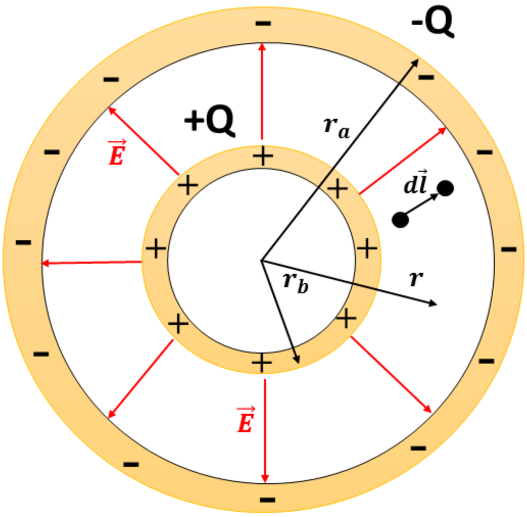


Figure 4.3. Two concentric spheres charged with opposite charges.

A hollow conducting sphere is placed concentrically in another conducting sphere of larger radius. The amount of net charge on the inner sphere surface is $+Q$ and the net charge on the outer sphere surface is $-Q$. The potential difference between inner and outer conducting spheres is given by;

$$V_{ba} = -\int_a^b \vec{E} \cdot d\vec{l}\ . \tag{4.6}$$

The electric field of a charged sphere depends on the distance r from the center of the sphere. Because $\vec{E}$ is parallel to $\vec{dl}$, the angle between them is zero and this gives $\cos\theta = \cos 0°$. The magnitude of the electric field E between the spheres $(r_b \langle r \langle r_a)$ is as follows;

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2} \cdot \tag{4.7}$$

If Eq. 4.7 is substituted into Eq. 4.6, then the integral can be solved as follows:

$$V_{ba} = -\frac{Q}{4\pi\varepsilon_0}\int_{r_a}^{r_b}\frac{dr}{r^2} \tag{4.8}$$

$$V_{ba} = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{r_b} - \frac{1}{r_a}\right) \tag{4.9}$$

$$V_{ba} = \frac{Q}{4\pi\varepsilon_0}\left(\frac{r_a - r_b}{r_a r_b}\right). \tag{4.10}$$

The capacitance of this spherical capacitor is given by;

$$C = \frac{Q}{V_{ba}} = 4\pi\varepsilon_0\left(\frac{r_a - r_b}{r_a r_b}\right). \tag{4.11}$$

The units of charge, potential difference, and capacitance are coulomb (C), volt (V), and farad (F), respectively. Hence,

$$1\,\mathrm{F} = \frac{1\,\mathrm{C}}{1\,\mathrm{V}} = 1\,\mathrm{C}^2/\mathrm{Nm}. \tag{4.12}$$

A conducting sphere can store electric charge. A conductor has an electrical potential due to its charge. If $V_a = 0$ at $r_a = \infty$, then potential V of a conducting sphere with radius r_b is as follows;

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r_b}. \tag{4.13}$$

Eq. 4.13 gives the potential of a conducting sphere which has a charge of Q and a radius of r_b. Consequently, the capacitance of an isolated conducting sphere of radius r_b at $r_a = \infty$ is given by;

$$C = \frac{Q}{V} \tag{4.14}$$

$$C = 4\pi\varepsilon_0 r_b. \tag{4.15}$$

As seen in Eq. 4.14, the charge of a conducting sphere Q is proportional to its potential V. This proportionality constant is called as "capacitance" and the capacitance of an isolated conducting sphere depends only on its radius.

The electric field E and potential V as a function of the distance r from the center of the sphere are shown in Figure 4.4.

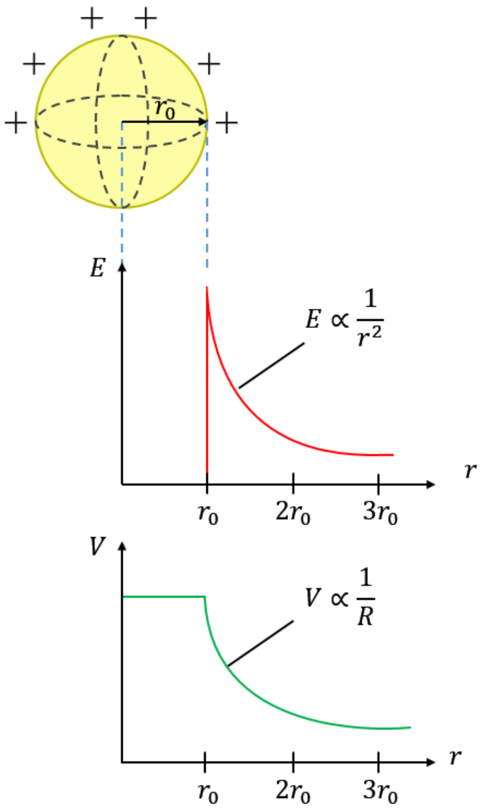


Figure 4.4. The electric field E and potential V as a function of the distance r.

If a hollow (or solid) conducting sphere with radius r_0 is charged, all of the electric charge is distributed on the outer surface of the sphere uniformly. For this reason, the electric charge is zero on the inner surface of the sphere and the electric field is also zero $(E = 0)$. Any point on the outer surface of the charged sphere has the maximum electric field.

If two conducting spheres are charged with the same charge $(Q_1 = Q_2 = Q)$, the magnitude of electrostatic force is as follows;

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{d^2}. \tag{4.16}$$

If the graph of $F = f\left(1/d^2\right)$ is plotted, the slope of the graph is as follows;

$$\text{Slope} = A = \frac{Q^2}{4\pi\varepsilon_0}. \tag{4.17}$$

Therefore, the permittivity of free space ε_0 is as follows;

$$\varepsilon_0 = \frac{1}{A}\frac{Q^2}{4\pi}. \tag{4.18}$$

PROCEDURE:

A. Electrostatics and Capacitance of a Conducting Sphere

A1. Set the assembly up as shown in Figure 4.5.

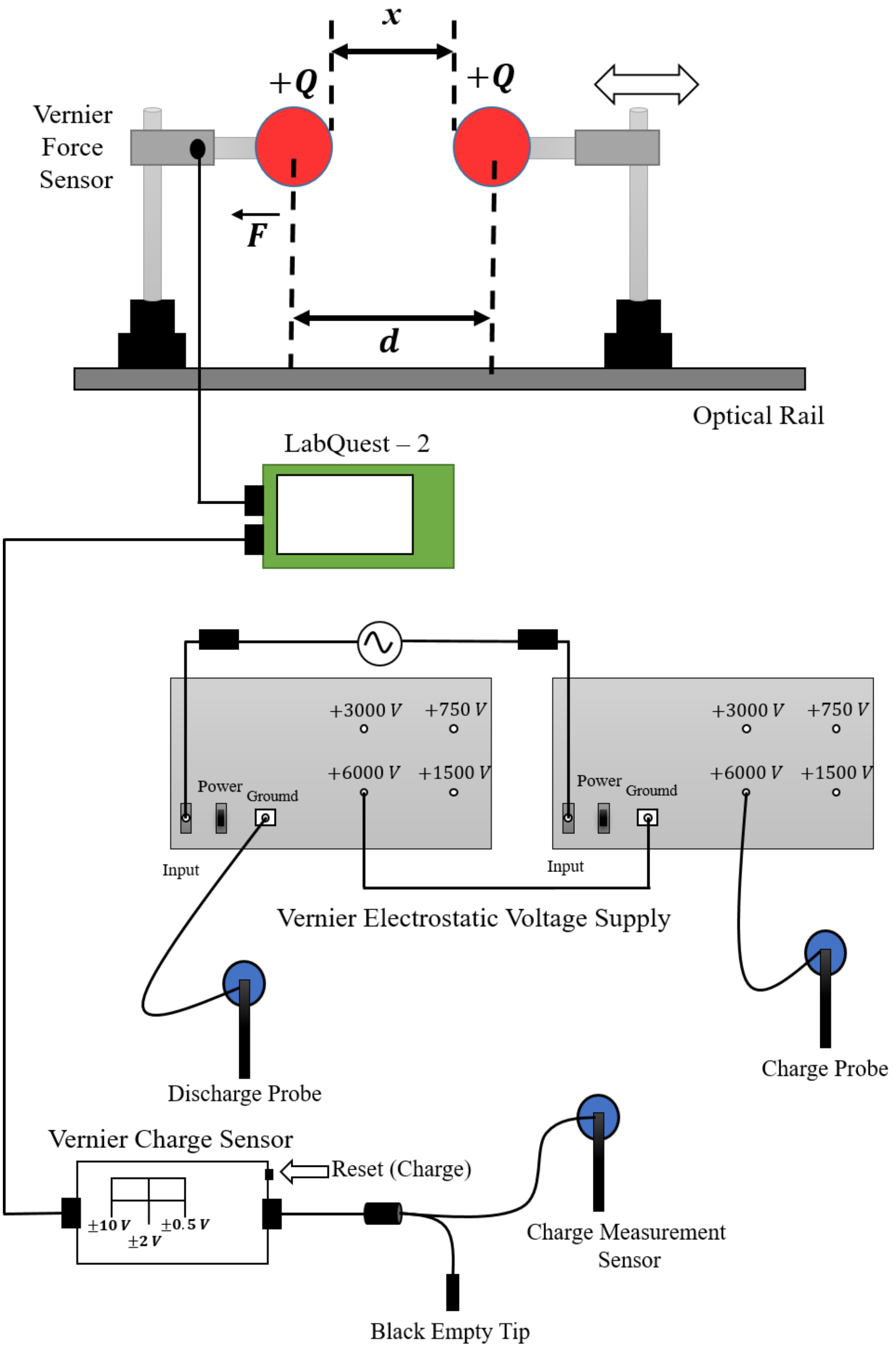


Figure 4.5. Experimental setup for electrostatics and Coulomb's Law.

High voltage power supplies are used in this experiment. Please strictly follow the instructions given to you during the experiment.

- Two identical conducting spheres of radius $\phi = 75$ mm are used in this experiment.
- Connect the force measurement sensor and charge measurement sensor to "CH – 1" input and "CH – 2" input of the LabQuest – 2 device, respectively.
- Set the stage switch on the force measurement sensor to "10 N".
- Set the stage switch on the charge measurement sensor to "± 10 V".
- Turn on the LabQuest – 2 measurement device. LabQuest – 2 measurement device will automatically identify the force (CH – 1) and charge (CH – 2) sensors (see Figure 4.5).

A2. Two conducting charged spheres must be discharged **<u>prior to the experiment</u>**.

- Set the movable sphere at a maximum distance on the rail.
- Switch the electrostatic voltage supply on.
- Get the **<u>discharge probe</u>** in touch with the spheres separately about $2-3$ s (Figure 4.6 (a)).

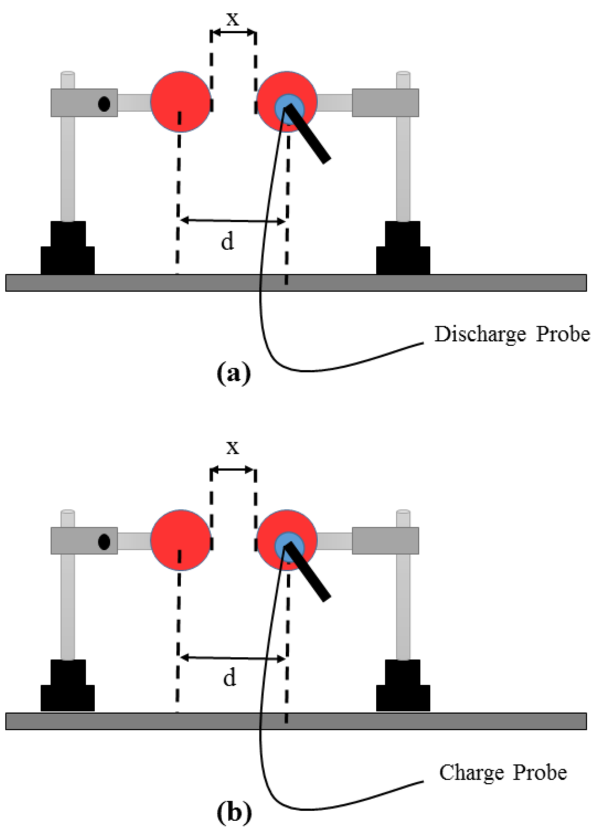


Figure 4.6. (a) Discharge and **(b)** charge processes of the conducting sphere.

A3. To apply 6 kV voltage, bring the **<u>charge probe</u>** in contact with the sphere at the maximum distance on the rail about $4-5$ s (see Figure 4.6 (b)).

- When the conducting sphere is charged, remove the probe from the sphere surface and switch off the electrostatic voltage supply.
- Shortly after the sphere is charged, push the “ZERO” (Reset) button on the charge measurement sensor to reset the operation of the charge measurement sensor.
- Bring the charge measurement sensor in contact with the charged sphere.
- Read the amount of charge $Q_{\exp}$ on LabQuest – 2 measurement device and record it in Table 4.1.

A4. Use Eq. 4.15 to calculate the capacitance of the conducting sphere C and record it in Table 4.1.

A5. Use Eq. 4.14 to calculate the amount of charge on the conducting sphere Q_t and record it in Table 4.1.

A6. Compare the measured charge $Q_{\exp}$ with the calculated charge Q_t.

A7. Repeat the same procedure for 12 kV voltage.

B. Coulomb’s Law

B1. Set the assembly up as shown in Figure 4.5.

- Determine the zero point on the distance between the two spheres.
- Choose this point as a reference point.

B2. Adjust the distance between the spheres as $x = 5$ mm by moving the mobile sphere (see Figure 4.7). Thus, the distance between the centers of the spheres will be $d = 80$ mm, record this value in Table 4.2.

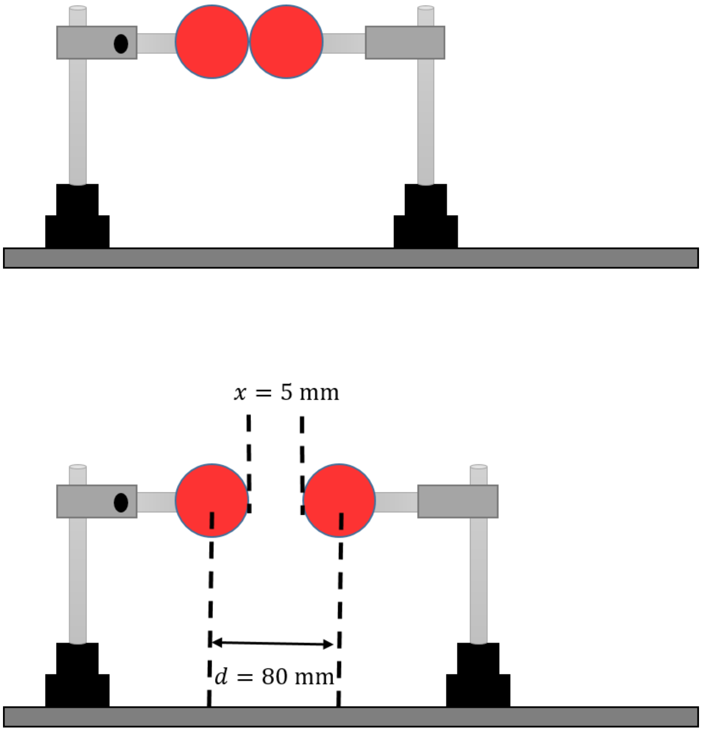


Figure 4.7. Adjusting the distance d between the spheres.

B3. Charge the spheres with 12 kV voltage using the charge probe according to the following steps:

- Switch on the Vernier voltage supply. Before charging the first sphere with the charge probe, adjust the following steps on the LabQuest – 2 home screen:
  CH 1: Force
  ZERO "Reset"
  Okay
- Charge the first sphere using the charge probe.
- Then adjust the following steps from the LabQuest – 2 home screen:
  CH 1: Force
  ZERO "Reset"
  Okay
- Charge the second sphere using the charge probe.
- Shortly after charging the two spheres, switch off the high voltage supplies.

B4. Read the force value on LabQuest – 2 home screen and record it in Table 4.2. Repeat the same measurement for three times, calculate the average value F_{avg} and record it in Table 4.2.

B5. Repeat the same procedure for the distances $x = 10$ mm and $x = 15$ mm.

B6. Plot the graph of $F_{avg} = f\left(1/d^2\right)$ using the experimental data in Table 4.2.

B7. Calculate the permittivity of free space and record it in Table 4.2**.**

> For all distances of the movable sphere, each sphere must first be **discharged** and then they must be **charged**. Shortly after charging the spheres, the charge sensor must be **reset** (ZERO). After this process, the total amount of charge on each sphere must be measured with the charge measurement probe. It's very important that when you measure the charge with the charge measurement probe, switch **"OFF"** the high voltage supply. Never bring the charge and discharge probes in touch with the spheres at the same time.

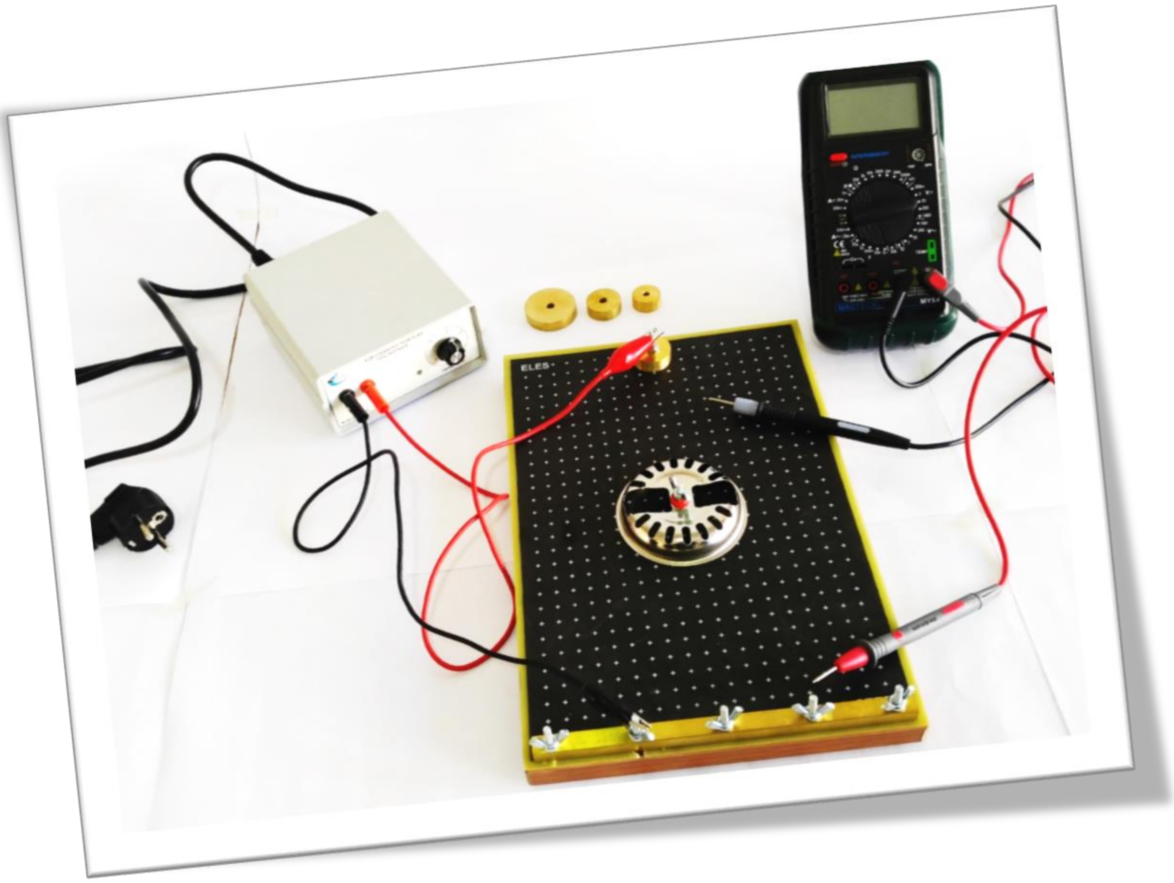
EXPERIMENTAL DATA:

TABLE 4.1					
r (m)	Voltage (kV)	Charge Q_{exp} (nC)	Capacitance C (F)	Charge Q_t (nC)	ΔQ

TABLE 4.2						
Distance d (m)	Force F (N)		F_{avg} (N)	$1/d^2$ (m^{-2})	Slope A^*	$\varepsilon_0{}^*$
	I. Reading					
	II. Reading					
	III. Reading					
	I. Reading					
	II. Reading					
	III. Reading					
	I. Reading					
	II. Reading					
	III. Reading					

* Do not forget to denote the units when you write their numerical values.

EQUIPOTENTIAL and ELECTRIC FIELD LINES



E5

EQUIPOTENTIAL and ELECTRIC FIELD LINES

E5

PURPOSE OF THE EXPERIMENT:

1. To investigate and map the equipotential lines of two oppositely charged conductors.

2. To map the electric field lines using the equipotential lines.

EQUIPMENT FOR THE EXPERIMENT:

Centimetric carbon sheet

DC power supply

Multimeter

Connection cables

Solid aluminium ring connecting part

Solid aluminium bar connecting part

Millimetric graphic paper

THEORY:

Electric field $\vec{E}$ at a point in space is defined as the electric force $\vec{F}$ acting on a positive test charge q_0 placed at that point divided by the test charge:

$$\vec{E} = \frac{\vec{F}}{q_0} \cdot \tag{5.1}$$

SI unit of electric field is newton per coulomb (N/C). As shown in Figure 5.1, the direction of the electric field $\vec{E}$ at a point A is the same as that of the force on a positive test charge q_0 placed at the point A.

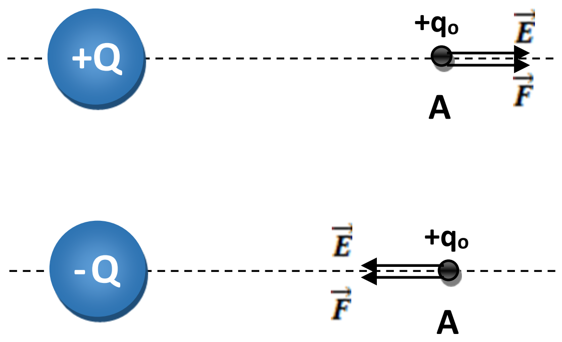


Figure 5.1. The electric field $\vec{E}$ due to $\pm Q$ charges and electrical force $\vec{F}$ on positive test charges $+q_0$ placed at points A.

The electric field lines are schematic representation of intensity and direction of the electric fields produced by charge distributions at different points in space. Electric field lines are imaginary lines and related to the electric field in the following manner:

i. The electric field vector $\vec{E}$ is tangent to the electric field line at every point.

ii. The number of lines per unit area through a surface perpendicular to the electric field lines are proportional to the magnitude of the electric field in that region. Therefore, as shown in Figure 5.2, when the field lines are close together, the electric field is strong and when they are far apart the electric field is weak.

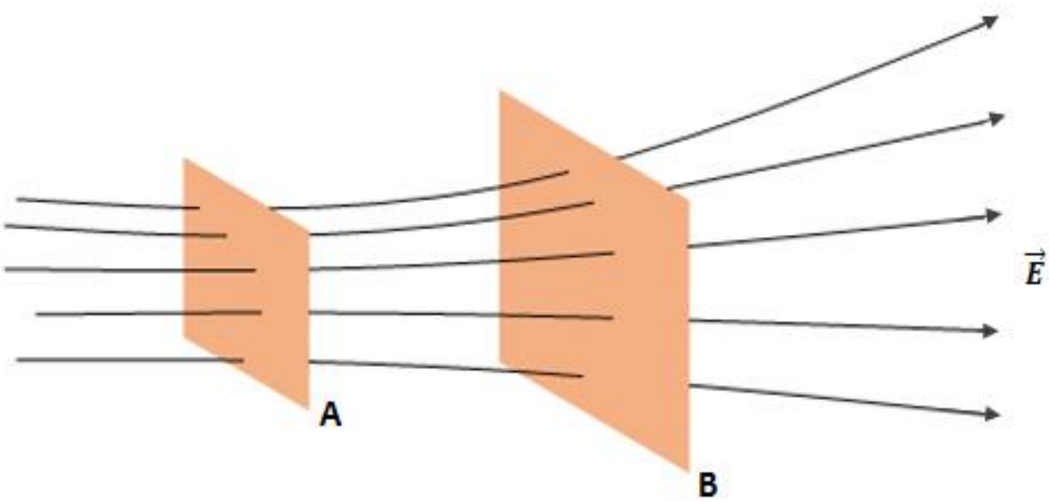


Figure 5.2. Electric field lines penetrating two surfaces A and B (A<B).

The rules for drawing electric field lines are as follows:

i. The lines must begin on a positive charge and terminate on a negative charge. In the case of an excess of one type of charge, some lines will begin or end infinitely far away. Figure 5.3 (a) and Figure 5.3 (b) show the electric field lines of a positive charge and a negative point charge, respectively. Figure 5.3 (c) shows the electric field lines of a positive and a negative point charges. Figure 5.3 (d) shows the electric field lines of two positive point charges. Figure 5.3 (e) shows the electric field lines between positive and negative linear charge densities.

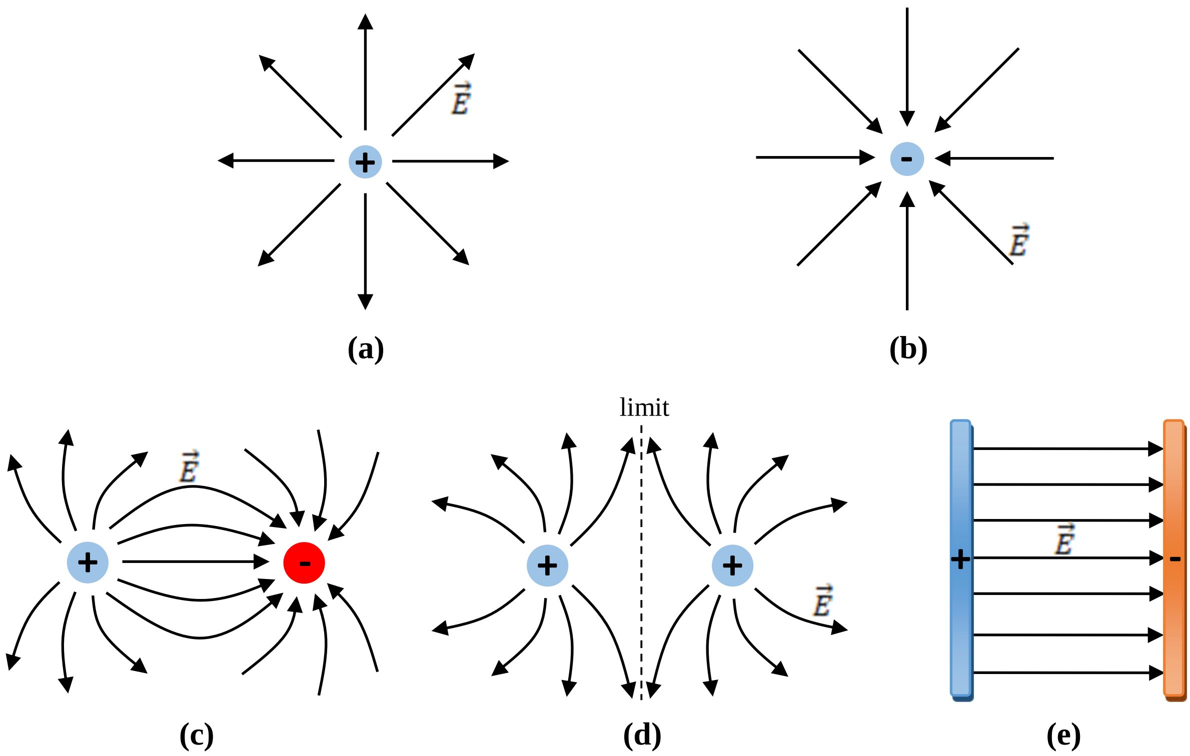


Figure 5.3. Electric field lines of **(a)** a single positive point charge, **(b)** a single negative point charge, **(c)** positive and negative point charges **(d)** two positive point charges, and **(e)** positive and negative linear charge densities.

ii. The number of lines leaving a positive charge or approaching a negative charge is proportional to the magnitude of the charge. In Figure 5.4, a two-dimensional drawing shows the electric field lines between charge $+ 3q$ and charge $– q$.

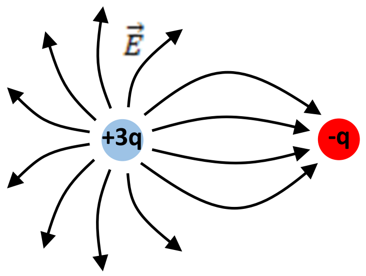


Figure 5.4. Electric field lines of charge + $3q$ and charge – q.

iii. No field lines can cross.

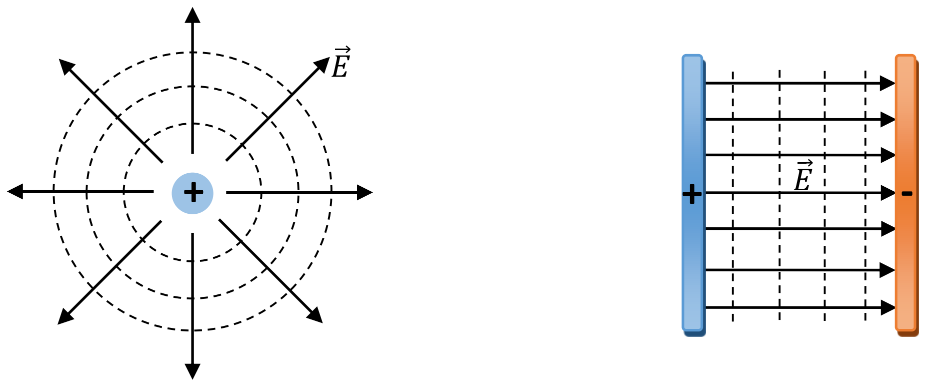
The electrostatic potential energy of a test charge q_0 placed at a point A in the vicinity of a charge distribution is defined as the work done in order to bring that charge from infinity to the point A. As given in Eq. 5.2, the electrostatic potential energy difference between any two points A and B is defined as the work done to move a charge from A to B.

$$U_{BA} = U_B - U_A = W_{AB} \quad (5.2)$$

The "electrostatic potential" is the electrostatic potential energy per unit charge. As given in Eq. 5.3, the electrostatic potential difference or simply the potential difference V_{BA} between the points A and B will be just the electrostatic potential energy difference per unit charge between A and B:

$$V_{BA} = V_B - V_A = \frac{W_{AB}}{q_0}. \quad (5.3)$$

In an electrical field produced by a given charge distribution, there will be many points that have the same potential. These points are called as "equipotential points". If one locates all the equipotential points, and then joins them, one gets an "equipotential line". All points lying on an equipotential line will have the same potential and so the work done to move a charge between two points on an equipotential line will be zero. This means, in turn, that the equipotential lines of a given charge distribution should be perpendicular to the electric field lines. The dotted lines in Figure 5.5 (a) and Figure 5.5 (b) represent the equipotential lines of a single positive point charge and two different line charge distributions.



(a) **(b)**

Figure 5.5. Electric field and equipotential lines of **(a)** a single positive point charge and **(b)** two linear charge distributions (equipotential lines are shown as dotted lines).

PROCEDURE:

A. Electric Field Lines of Two Point Charges and Equipotential Lines

A1. Connect the cables of the DC power supply (in OFF position) to the solid aluminium rings.

A2. Connect one of the cables of the multimeter (in OFF position) to the solid aluminium ring, while the other cable is disconnected as shown in Figure 5.6.

A3. Draw the solid aluminium rings on a millimetric graph paper by taking the "+" marks of the centimetric carbon sheet which is given in Figure 5.6 as a reference.

A4. Switch on the multimeter and adjust the measurement range to 10 V DC.

A5. Switch on the DC power supply and adjust the voltage level to 10 V.

A6. As shown in Figure 5.6, identify the 2-, 4-, 6-, and 8-V points on the blue dotted line with a multimeter by sliding the probe over the carbon sheet. Mark the identified points on the millimetric graph paper.

A7. Identify the 2-, 4-, 6-, and 8-V points at 2, 4, 6, and 8 cm parallel distances on both side of the symmetry line with a multimeter by sliding the probe over the carbon sheet. Mark the identified points on the millimetric graph paper.

A8. Combine the equipotential points of these potentials to obtain the equipotential lines on the millimetric graph paper.

A9. Obtain the electric field lines on the millimetric graph paper by using these equipotential lines.

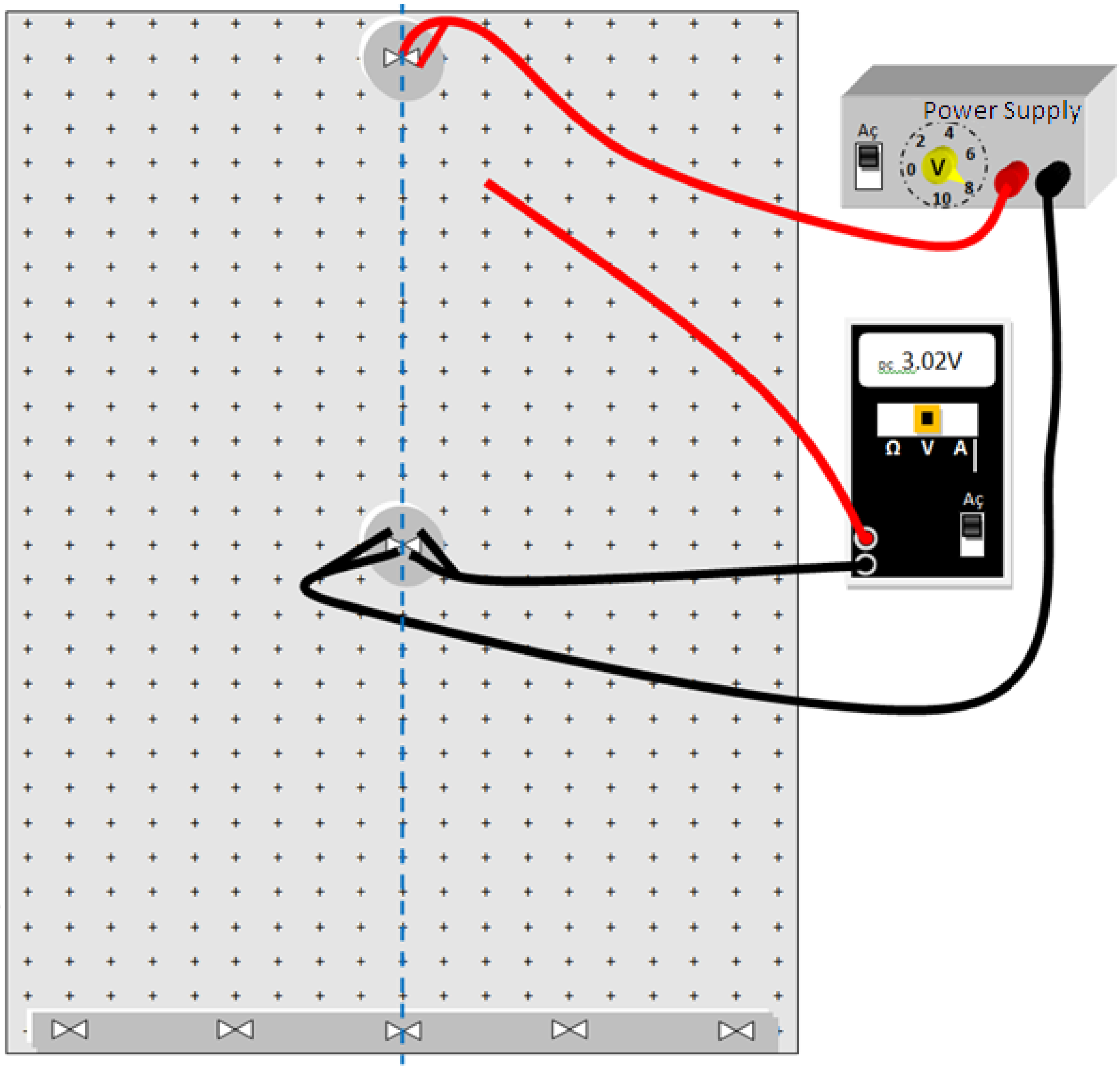


Figure 5.6. A circuit to determine the equipotential lines and electric field lines of two point charges.

B. Equipotential Lines and Electric Field Lines of a Point Charge and a Linear Charge Distributions

B1. Connect the cables of the DC power supply (in OFF position) as follows: one cable to the solid aluminium bar and the other one to the solid aluminium ring.

B2. Connect one of the cable of the multimeter (in OFF position) to the solid aluminium bar, while the other cable is disconnected as shown in Figure 5.7.

B3. Draw the solid aluminium ring and the solid aluminium bar on a millimetric graph paper by taking the "+" marks of the centimetric carbon sheet which is given in Figure 5.7.

B4. Switch on the multimeter and adjust the measurement range to 10 V DC.

B5. Switch on the DC power supply and adjust the voltage level to 10 V.

B6. As shown in Figure 5.7, identify the 2-, 4-, 6- and 8-V points on the blue dotted line with a multimeter by sliding the probe over the carbon sheet. Mark the identified points on the millimetric graph paper.

B7. Identify the 2-, 4-, 6- and 8-V points at 2, 4, 6, and 8 cm parallel distances on both side of the symmetry line with a multimeter by sliding the probe over the carbon sheet. Mark the identified points on the millimetric graph paper.

B8. Combine the equipotential points of these potentials to obtain the equipotential lines on the millimetric graph paper.

B9. Obtain the electric field lines on the millimetric graph paper by using these equipotential lines.

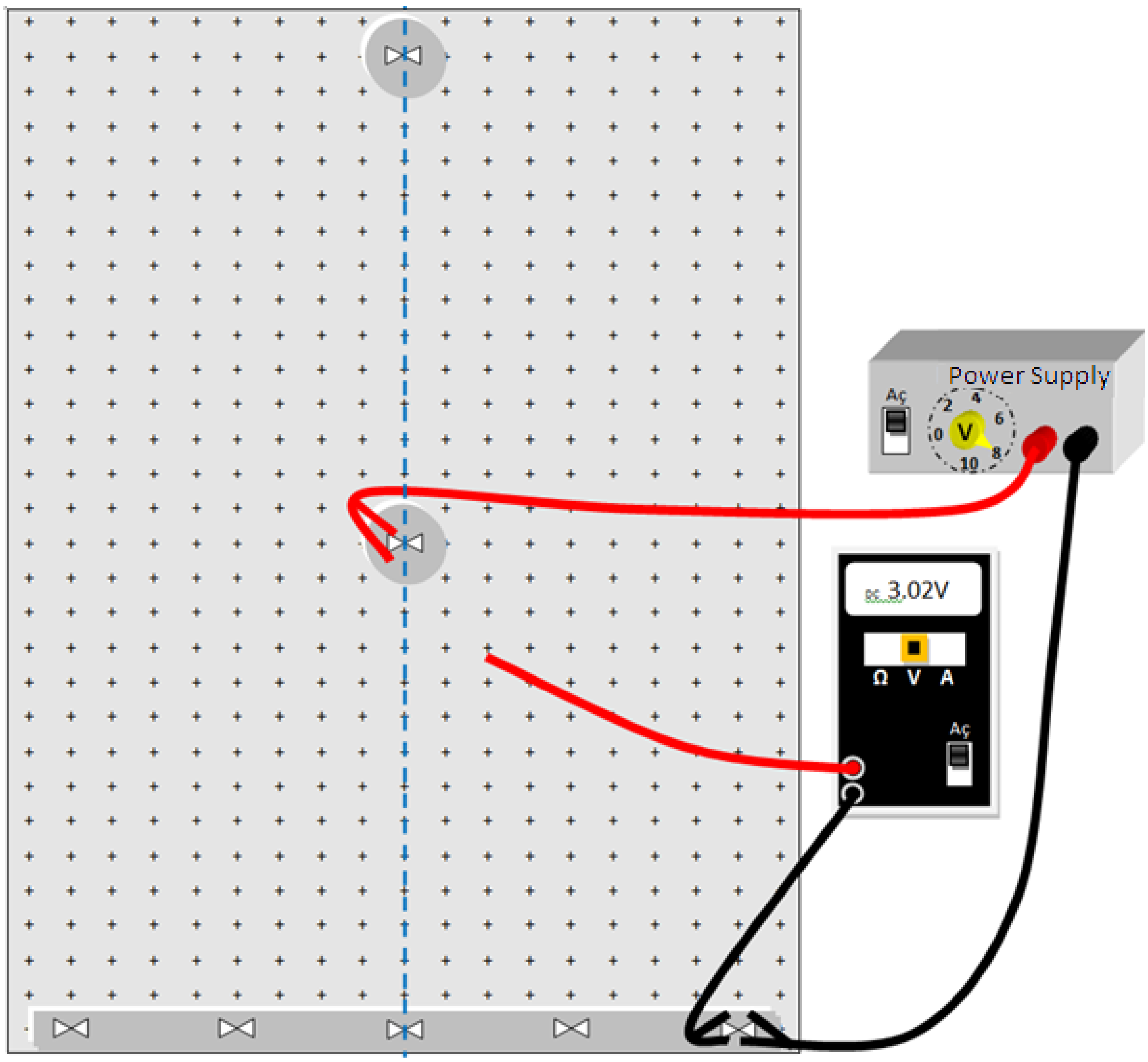


Figure 5.7. A circuit to determine the equipotential lines and electric field lines of a point charge and a linear charge distribution.

MAGNETIC FORCE

E6

MAGNETIC FORCE E6

PURPOSE OF THE EXPERIMENT:

To investigate magnetic force on a current-carrying wire in a magnetic field depending on current, magnetic field, and length of wire.

EQUIPMENT FOR THE EXPERIMENT:

Scale

6 U shaped magnets

Magnet holder

6 current circuits

Main unit that has attachment for the current circuits

DC power supply

Ammeter

Connection wires

THEORY:

An electric field is a field that surrounds a static electric charge. When the charge starts moving, a magnetic field will be created in addition to the electric field. Magnetic field at a given point can be described by magnetic force $\vec{F}_B$. As shown in Figure 6.1 (a), the magnetic force is a force that has an impact on a moving charged particle with a velocity of $\vec{v}$. If the particle moves parallel to the magnetic field, the magnetic force on the particle will be zero. On the other hand, if the particle moves perpendicular to the magnetic field, the magnetic force will be maximum. If positively and negatively charged particles move in the same direction in a magnetic field as shown in Figure 6.1 (b), the direction of the magnetic field on the positively charged particle is opposite to the direction of the magnetic field on the negatively charged particle.

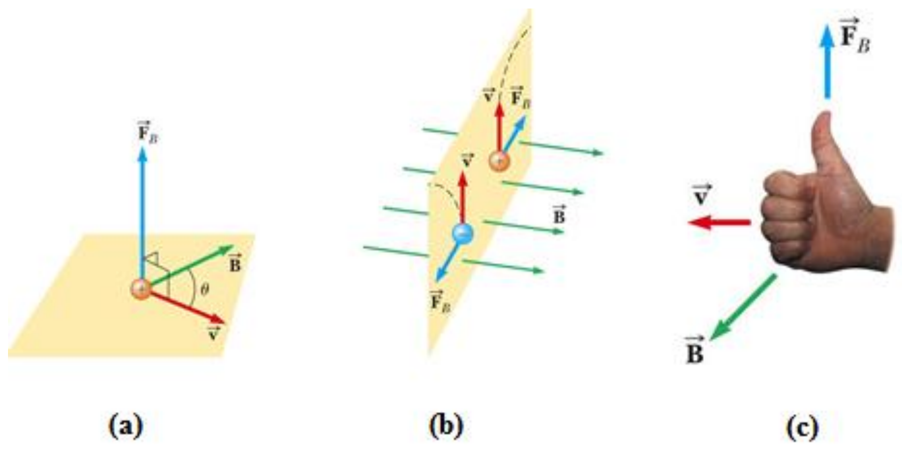


Figure 6.1. (a) Magnetic force on a positively charged particle that moves with a velocity of $\vec{v}$, **(b)** magnetic forces on positively and negatively charged particles that move with the same velocity, and **(c)** determination of the direction of magnetic force by right-hand rule.

As shown in Figure 6.1 (c), direction of the magnetic field can be determined by the right-hand rule. The direction of the thumb shows the direction of the magnetic field while the other four fingers are curled up from the velocity vector to the magnetic field vector. Magnetic force is given by

$$\vec{F} = q\vec{v}\times\vec{B} \tag{6.1}$$

where q is the charge of the particle, $\vec{v}$ is the velocity of the particle and $\vec{B}$ is the magnetic field.

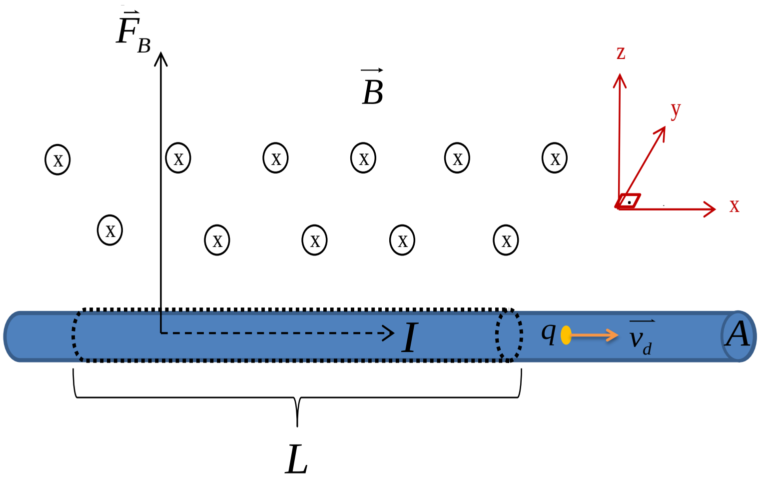


Figure 6.2. The magnetic force on a current-carrying wire in a constant magnetic field.

Now, let us consider a wire that carries a current I has a cross section A and a length L. This wire is placed in a constant magnetic field $\vec{B}$ directed into the page as shown in Figure 6.2. Total magnetic force on the charge carriers (positive holes) in the conductive wire is calculated by drift velocity $\vec{v}_d$ of the charge carriers, the number of the charge carriers N, and the magnetic field $\vec{B}$. Here, $N = nAL$ is the number of charge carriers on the selected volume of length L, n is the number of charge carriers per volume and AL is the selected volume of length L on the conductive wire as shown in Figure 6.2. Total charge on the selected volume will be Nq because the charge carriers are positively charged holes and total magnetic force is given by

$$\vec{F} = Nq\vec{v}_d \times \vec{B}$$

$$N = nAL$$

$$\vec{F} = nALq\vec{v}_d \times \vec{B}. \tag{6.2}$$

The magnitude of the current density is given by

$$j = nqv_d. \tag{6.3}$$

The current that passes through the conductive wire is found as

$$I = jA = nqv_d A. \tag{6.4}$$

The magnetic force can also be described in terms of current I and a displacement vector $\vec{L}$ in the same direction with the drift velocity $\vec{v}_d$ of the charge carriers (since $\vec{v}_d = v_d\hat{i}$, we have $\vec{L} = L\hat{i}$). If Eq. 6.3 and 6.4 are plugged into Eq. 6.2, the magnetic force is given by

$$\vec{F} = nqv_d A\vec{L} \times \vec{B}. \tag{6.5}$$

Now, Eq. 6.4 is plugged into Eq. 6.5, the magnetic force is given by

$$\vec{F} = I\,\vec{L} \times \vec{B}. \tag{6.6}$$

The direction of the displacement vector $\vec{L}$ is the same as the direction of the current. In Figure 6.2, as the charge carriers are the positively charged holes, magnitude of the magnetic force is given by

$$F = ILBsin\theta. \tag{6.7}$$

In this experiment, how magnetic force changes depending on the current, length of the wire, and the magnetic field will be investigated.

PROCEDURE:

Main parts used in this experiments and setup for the magnetic field experiment are shown in Figures 6.3 and 6.4, respectively.

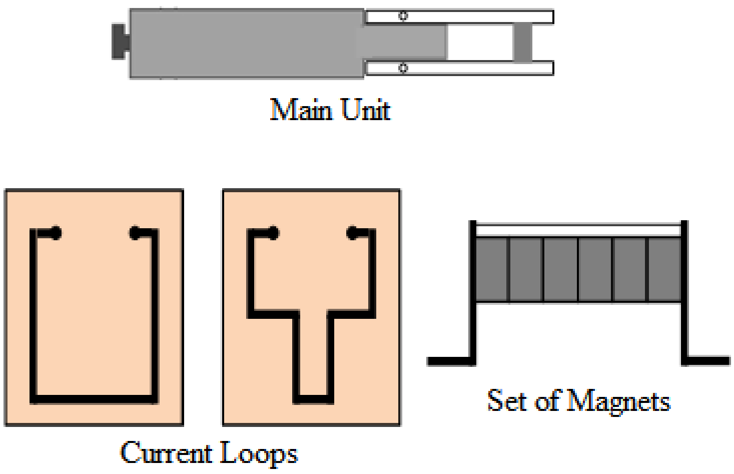


Figure 6.3. Main parts that are used in the experiment.

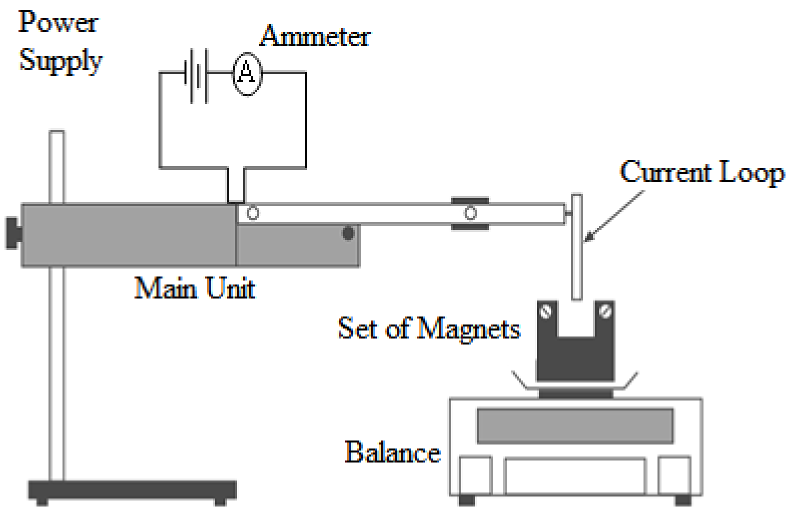


Figure 6.4. Setup for magnetic force experiment.

In this part of the experiment, how magnetic force changes by changing the current on the wire while the magnetic force and wire length are kept constant will be analyzed.

A. Constant Magnetic Field, Constant Wire Length, and Variable Current

A1. Decide which current loop and how many magnets you will use and record them in Table 6.2. The use of 6 magnets is suggested to take reliable measurements.

TABLE 6.1 Wire lengths of the current loops.	
Current Loops	Wire Length *L* (cm)
SF40	1.2
SF37	2.2
SF39	3.2
SF38	4.2
SF41	6.4
SF42	8.4

A2. Put U magnets into the magnet holder. Then, place the magnet holder on the balance while its arms are in upright position. Plug the selected current loop into the main unit arms. Place the current loop between the U magnets by moving the main unit. The current loop **must never touch** the magnets.

A3. Plug in the power supply.

A4. Check out the sensitive balance if it is balanced. If it is not balanced, balance it.

A5. Determine the masses of magnets and the magnet holder m when there is no current on the loop ($I = 0$) and record it in Table 6.2.

A6. Adjust the current to 0.5 A by using the power supply. The wire in the magnetic field will be exposed to a magnetic force due to the current passing through the wire. The mass of the magnet set will change due to this magnetic force. Determine the new mass of magnet set and record it in Table 6.2.

A7. Determine the mass difference Δm between the mass when a current passes through the wire and the mass when there is no current on the wire, and record it in Table 6.2.

A8. Calculate the force by using the equation $F = \Delta mg$ and record it in Table 6.2.

A9. Increase the current by 0.5 A in each time and repeat steps 6, 7, and 8. The current should be 5 A at maximum.

A10. Plot the graph of $F = f(I)$ by using the data in Table 6.2. Then, use the slope of the graph to find the magnitude of total magnetic field B and record it in Table 6.2.

B. Constant Magnetic Field, Constant Current, and Variable Wire Length

B1. In this section, variable wire length will be used while the magnetic field and the current are kept constant. Each loop has a different wire length as shown in Table 6.1. The effect of the magnetic field on different wire lengths will be studied when the current is 5 A.

B2. Place the magnet holder on sensitive balance. Plug in the first selected current loop to the main unit arms and place the current loop between U magnets. The current loop **must never touch** the magnets.

B3. Plug in the power supply.

B4. Determine the mass of magnets and the magnet holder m when there is no current on the loop ($I = 0$) and record it in Table 6.3.

B5. Adjust the current to 0.5 A by using the power supply.

B6. Due to the change in the mass of the magnet set, read out the new mass from the sensitive balance and record it in Table 6.3.

B7. Determine the mass difference Δm which is the difference between the mass when a current passes through the wire and the mass when there is no current and record Δm in Table 6.3.

B8. Calculate the force by using the equation $F = \Delta mg$ and record it in Table 6.3.

B9. Turn off the power supply to cut off the current. Take out the current loop and plug in another current loop. Then repeat the same procedure from step 5 to step 9.

B10. Plot the graph of $F = f(L)$. Find the magnitude of magnetic field by using the slope of the graph and record it in Table 6.3.

C. Constant Current, Constant Wire Length, and Variable Magnetic Field

C1. In this part, the wire length and the current will be kept constant by choosing a specific current loop and adjusting the current up to 5 A. The change of magnetic force on the wire will be investigated when the current loop is placed into a variable magnetic field that is created by changing the number of magnets.

C2. Place the magnet holder on the sensitive balance. Plug in the first selected current loop to the main unit arms and place the current loop between U magnets. The current loop **must never touch** the magnets.

C3. Plug in the power supply.

C4. Determine the mass of magnets and the magnet holder m when there is no current on the loop ($I = 0$) and record it in Table 6.4.

C5. Adjust the current to 5 A by using the power supply.

C6. Due to the change in the mass of the magnet set, read out the new mass from the sensitive balance and record it in Table 6.4.

C7. Determine the mass difference Δm which is the difference between the mass when a current passes through the wire and the mass when the current is zero and record it in Table 6.4.

C8. Calculate the force by using the equation $F = \Delta mg$ and record it in Table 6.4.

C9. Calculate the magnitude of the magnetic field B by using the force F, wire length L, and the current I and record it in Table 6.4.

C10. Turn off the power supply to cut off the current. Add one more magnet on the magnet holder in each step and repeat the same procedure from step 4 to step 10.

C11. Make comments on your results.

EXPERIMENTAL DATA:

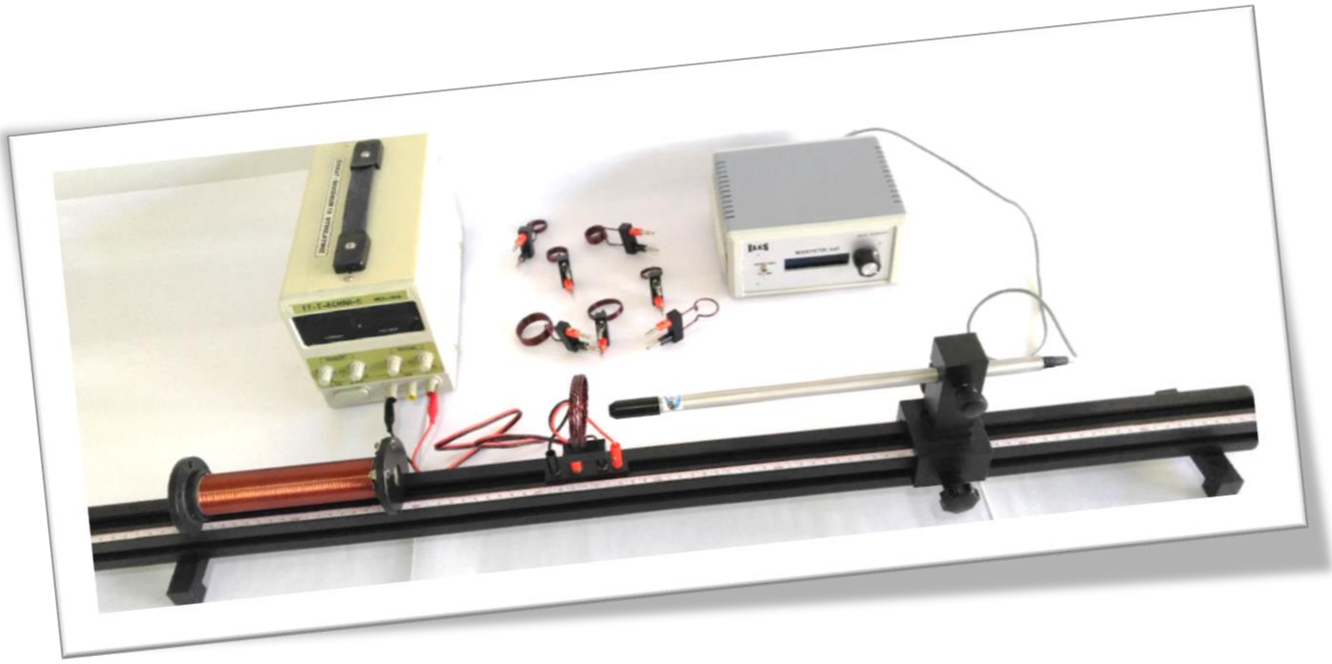
TABLE 6.2							
Number of Magnets = ………				Wire Length L = …………cm			
I (A)	m (g)	Δm (g)	F (N)	I (A)	m (g)	Δm (g)	F (N)
0				3.0			
0.5				3.5			
1.0				4.0			
1.5				4.5			
2.0				5.0			
2.5							
Total Magnetic Field B *= ………..							

TABLE 6.3				
Number of Magnets = …..	Current I = 5 A		For $I = 0$, m = ……… g	
Current Loop	L (cm)	m (g)	Δm (g)	F (N)
SF40				
SF37				
SF39				
SF38				
SF41				
SF42				
Total Magnetic Field B *= ………..				

TABLE 6.4					
Wire Length L = …………. cm			Current I = 5 A		
Number of Magnets	[I = 0] m (g)	[I = 5 A] m (g)	Δm (g)	F (N)	B*
1					
2					
3					
4					
5					
6					

* Do not forget to denote the units when you write their numerical values.

BIOT-SAVART LAW



E7

BIOT-SAVART LAW

E7

PURPOSE OF THE EXPERIMENT:

1. To measure the magnetic field of a circular conducting wire with flowing current and to investigate the variation of magnetic field with wire radius and the number of turns.
2. To determine the magnetic field of a coil with flowing current at its center and at various distances from the center.

EQUIPMENT FOR THE EXPERIMENT:

DC Power supply

Teslameter

Coil

Circular conducting wires with different number of turns

Optical axis

THEORY:

7.1. BIOT-SAVART LAW

The magnetic field generated by a point charge q moving with velocity $\vec{v}$ is given by

$$\vec{B} = \frac{\mu_0}{4\pi}\frac{q}{r^2}(\vec{v}\times\hat{r})\cdot \qquad (7.1)$$

The magnetic fields produced by currents flowing on wires are of much greater practical interest than the magnetic field produced by a single point charge. A current on a wire is a distribution of moving point charges, each of which produces its own individual magnetic field. According to the superposition principle, the magnetic field of a current is then the sum or the integral of all the individual magnetic fields of all the individual point charges.

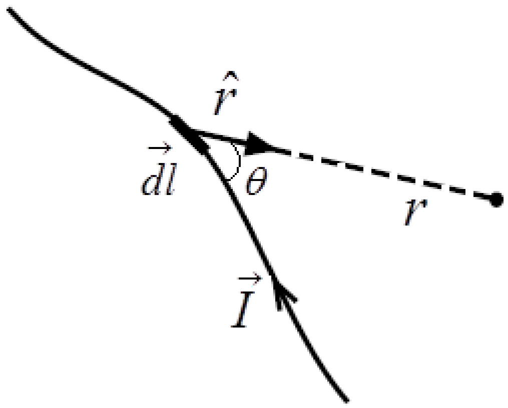


Figure 7.1. Wire carrying a current I .

Figure 7.1 shows a thin wire of arbitrary shape carrying a steady current I . Following the usual convention, we will pretend that the current is due to a flow of positive charge. Consider a small segment dl of this wire. We can regard the moving charge dq within dl as a point charge which produces a magnetic field,

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{dq}{r^2}(\vec{v}\times\hat{r}) \tag{7.2}$$

with a magnitude

$$dB = \frac{\mu_0}{4\pi}\frac{dq}{r^2}v\sin\theta \tag{7.3}$$

where θ is the angle between $\vec{v}$ and $\hat{r}$ (Figure 7.1). To relate dq to the current, we begin with the definition of the current,

$$dq = Idt. \tag{7.4}$$

Here dt is the time it takes the charge dq to flow out of the small segment dl , that is,

$$dt = dl / v. \tag{7.5}$$

Hence,

$$dq = Idl / v\ . \tag{7.6}$$

With this, Eq. 7.3 becomes,

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{r^2}\cdot \tag{7.7}$$

To put this in a vector form, we treat the segment of wire as a vector dl tangent to the wire and in the direction of the current (see Figure 7.1). The magnetic field in Eq. 7.2 can then be expressed as;

$$\vec{dB} = \frac{\mu_0 I}{4\pi} \frac{\vec{dl} \times \hat{r}}{r^2}. \tag{7.8}$$

Eq. 7.8 gives the magnetic field generated by a short segment of a wire. It is called as the "Biot-Savart Law". The magnetic field generated by a wire of any length and shape can be calculated by integrating Eq. 7.8 along the wire.

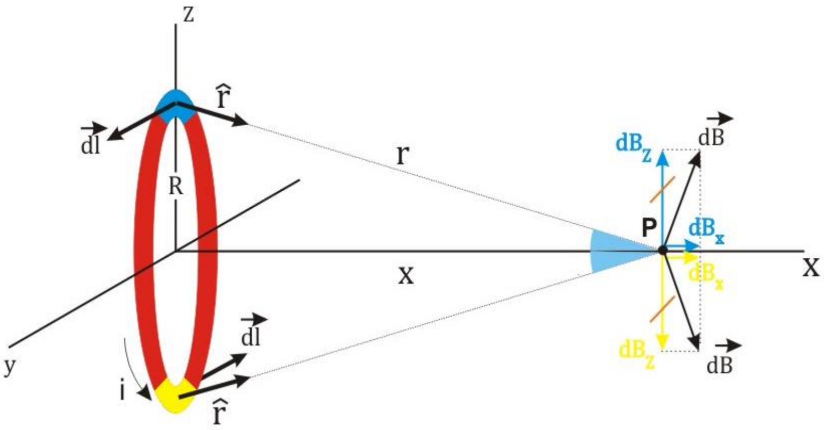


Figure 7.2. Magnetic field of a circular wire loop carrying a current *I* in the *y*-*z* plane.

Magnetic field of a circular wire loop carrying a current *I* at a distance x along from its center is calculated by integrating Eq. 7.8 (see Figure 7.2):

$$B(x) = N\mu_0 \frac{I}{2} \frac{R^2}{\left(x^2 + R^2\right)^{3/2}}. \tag{7.9}$$

Magnetic field at the coil center ($x = 0$) then becomes

$$B(x) = \frac{\mu_0 NI}{2R}, \tag{7.10}$$

where the magnetic permeability constant is $\mu_0 = 4\pi \times 10^{-7}\,\text{Tm/A}$.

PROCEDURE:

A. Measurement of Magnetic Field of a Circular Conducting Wire

Firstly, magnetic fields of circular conducting wires with different number of turns and with different radii are measured. Then the magnetic permeability constant μ_0 is calculated from the measured data. Now, connect the circuit as shown in Figure 7.3.

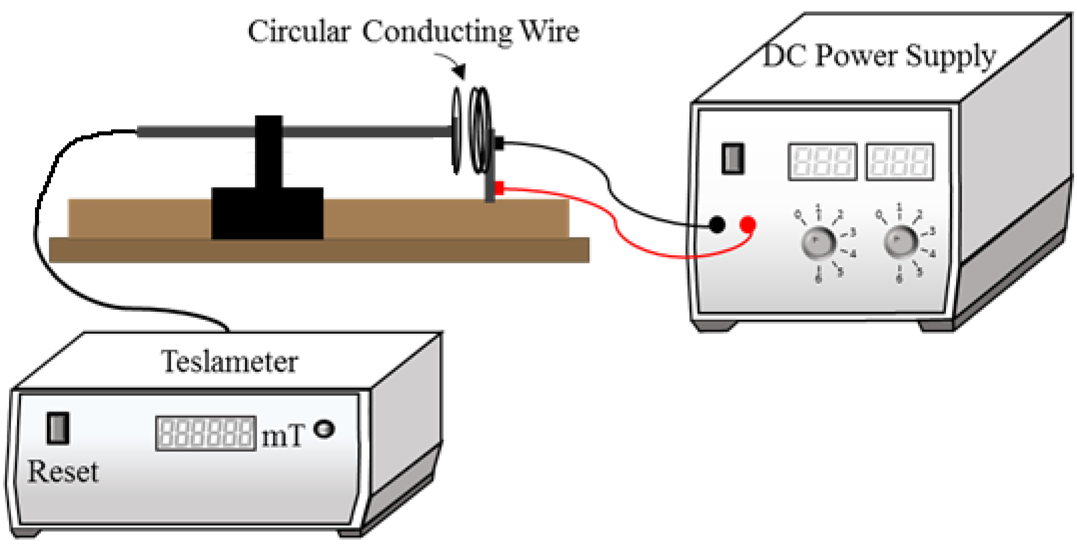


Figure 7.3. Experimental setup to measure magnetic field of a circular conducting wire.

A1. Place the circular wire with radius $R = 3$ cm and $N = 1$ number of turns to the holder on the experimental setup (see Figure 7.3).

A2. Align the Hall probe sensor of the teslameter to the center of the coil by moving it on the optical axis (x).

A3. Connect the coil ends to the DC power supply.

A4. Turn on the DC power supply.

A5. Adjust the current to $I = 1$ A. Note that the current should stay constant and it should not exceed 2 A throughout the experiment. Otherwise, the wires will overheat.

> Maximum applied current should be 2 A. Do not touch the circular wires and complete the experiment as soon as possible.

A6. Before switching the teslameter on, choose the reset button and after switching the teslameter on, adjust it to zero value.

A7. Bring the Hall probe to the center of the circular conducting wire and then read the magnetic field value on the teslameter and record it in Table 7.1.

A8. Similarly, repeat magnetic field measurements for the circular conducting wires of the same radius R but with different number of turns N = 2, 3, 4, 5 and record them in Table 7.1.

A9. Plot the graph of $B = f(N)$ using the data in Table 7.1.

A10. Calculate the magnetic permeability constant μ_0 by using the slope of the graph and Eq. 7.10.

A11. Similarly, repeat magnetic field measurements for three conducting wires of different radii but the same $N = 4$ number of turns and record them in Table 7.2.

A12. Plot the graph of $B = f(1/R)$ using the data in Table 7.2.

A13. Calculate the magnetic permeability constant μ_0 by using the slope of the graph and Eq. 7.10.

A14. Compare μ_0 values obtained from both graphs.

B. Measuring the Magnetic Field in a Coil

B1. Connect the circuit as shown in Figure 7.4.

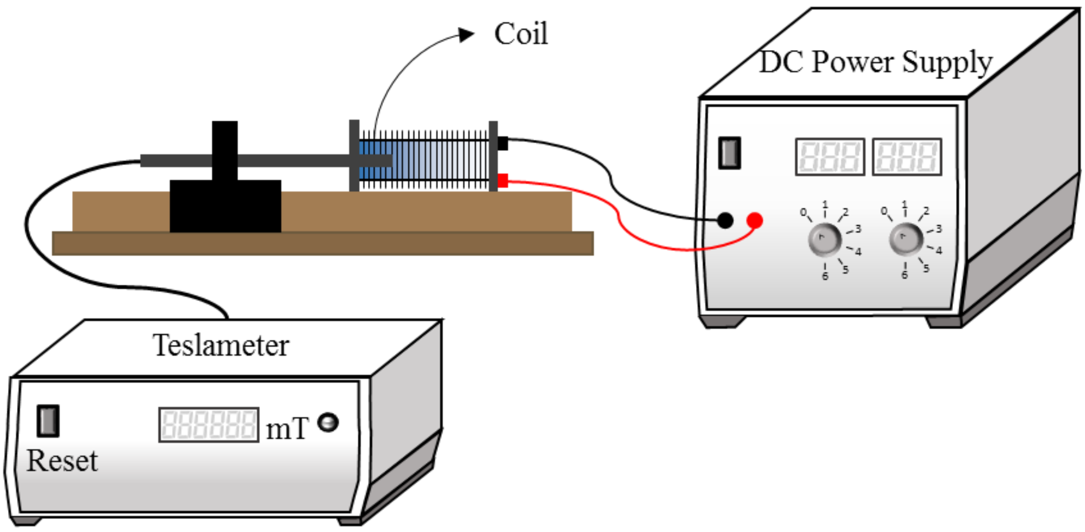


Figure 7.4. Experimental setup to measure the magnetic field in a coil.

B2. Switch the DC power supply on. Adjust the current to $I = 1\ \text{A}$. Note that the current should stay constant and it should not exceed 2 A throughout the experiment. Otherwise, the wires will overheat.

> Maximum applied current must be 2 A. Don't touch circular wires and complete the experiment as soon as possible.

B3. Before switching the teslameter on, choose the reset button and after switching the teslameter on, adjust it to zero value.

B4. Place the Hall probe at the end of the coil. Make sure that the probe stays at the center of the coil ($x = 0\ \text{cm}$).

B5. Using a reference point on the attachment of the holder to the optical axis, move the Hall probe slowly into the coil for 1-cm intervals.

B6. Read the magnetic field values B on the teslameter for 1-cm intervals and record them in Table 7.3.

B7. Plot the graph of $B = f(x)$ using the data in Table 7.3 and comment on your results.

EXPERIMENTAL DATA:

TABLE 7.1		
R (cm)	*N*	*B* (mT)
.....	1	
	2	
	3	
	4	
	5	

TABLE 7.2		
N	*R* (cm)	*B* (mT)
4		

TABLE 7.3		
N	*x* (cm)	*B* (mT)
250	0	
	1.0	
	2.0	
	3.0	
	4.0	
	5.0	
	6.0	
	7.0	
	8.0	
	9.0	
	10.0	

TRANSFORMER

E8

TRANSFORMER

E8

PURPOSE OF THE EXPERIMENT:

To study electrical characteristics of a transformer.

EQUIPMENT FOR THE EXPERIMENT:

Two coils of 500 and 1000 windings and a transformer core

2 AC Ammeters (0 – 1 A)

2 AC Potentiometers (0 – 250 V)

4 lamps

A box in which the lamps will be placed

Connection cables

THEORY:

An electric current that reverses direction in time periodically and having a magnitude that varies continuously is called alternating current. Commonly used alternating current is the one that has a variation of magnitude with a simple sinus function and hence it is also called sinusoidal alternating current. The electric energy that is used in our houses and in industry is a sinusoidal alternating current. A transformer is a device used to increase and decrease voltages in case of necessity without changing the power. Its physical origin lies in electromagnetic induction. Transformers consist of two and sometimes more number of reels (coils) that are rolled on a core made up of soft iron. The core is not made up of pure iron in order to prevent energy loss that results from Foucault currents (loops of electrical current induced within conductors by a changing magnetic field in the conductor), and instead it is made by piling thin iron plates that are insulated from each other and by compressing them.

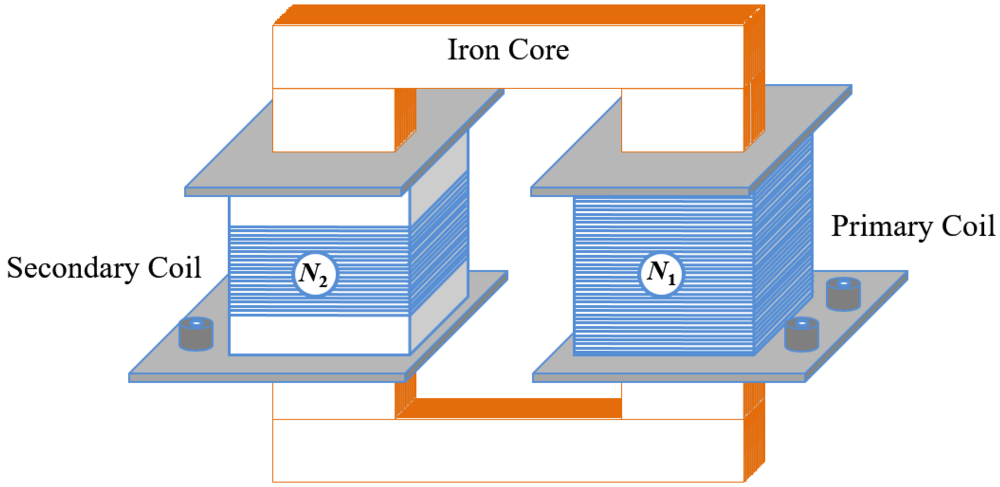


Figure 8.1. Structure of a transformer.

The coil on which an electric energy is applied is called 1st circuit (primary), and the coil from which an electric energy is extracted is called 2nd circuit (secondary). A transformer without an energy loss on the iron core and the coils, i.e., no electric energy loss into thermal energy, is called an ideal transformer. In an ideal transformer the following relation applies:

$$I_1V_1 = I_2V_2\,. \tag{8.1}$$

Furthermore we can write

$$\frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{N_1}{N_2} \tag{8.2}$$

where N_1 is the number of windings of the primary coil and N_2 is the number of windings of the secondary coil. Here, the ratio N_1/N_2 is called the rate of change. If $N_1 < N_2$ then $V_1 < V_2$ and this transformer is named as a step-up transformer. If $N_1 > N_2$ then, $V_1 > V_2$ and this transformer possess a step-down property. The efficiency of a transformer is obtained by the ratio of the power obtained from the transformer to the power supplied to the transformer:

$$\text{Efficiency} = \frac{\text{Power on Secondary}}{\text{Power on Primary}} = \frac{P_2}{P_1} = \frac{I_2V_2}{I_1V_1}\,. \tag{8.3}$$

PROCEDURE:

> ⚠ The system works with 220 volts. Do not apply current to the circuit without the supervision of the laboratory attendant.

1. Set the circuit up as shown in Figure 8.2 ($N_1 = 1000$ turns, $N_2 = 500$ turns).

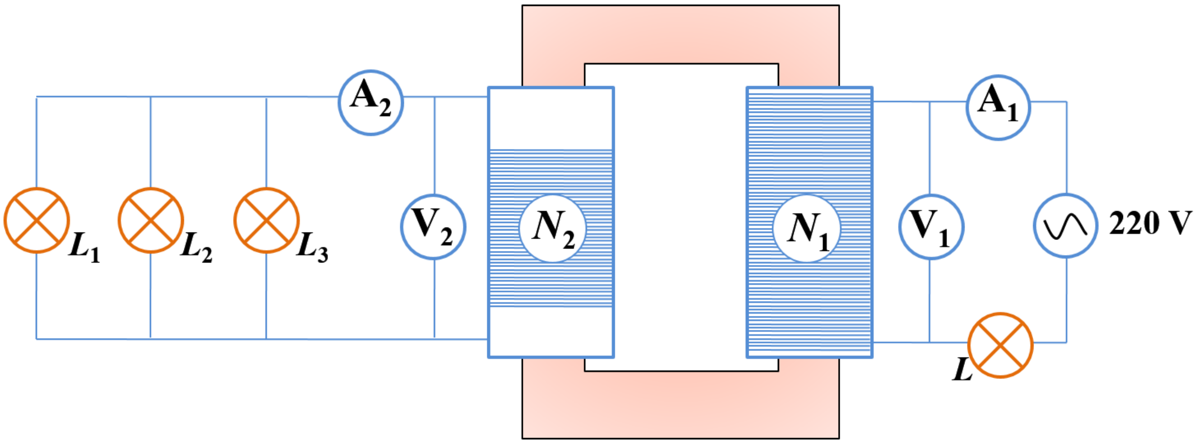


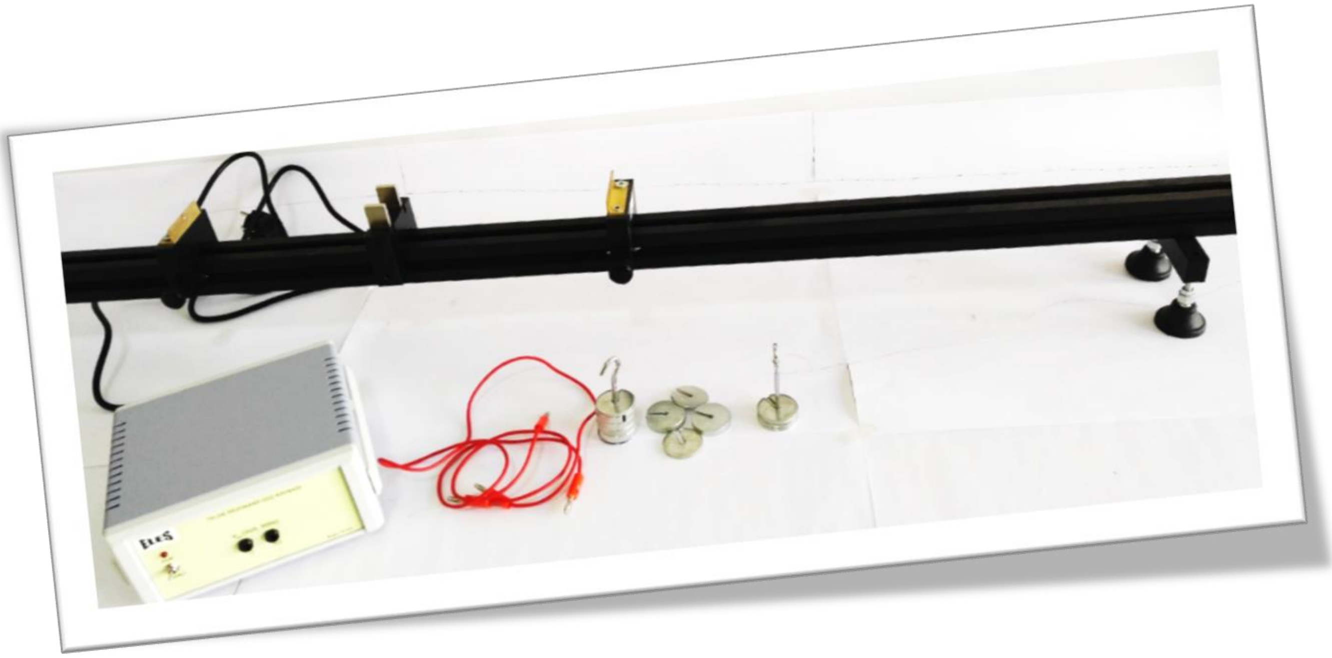
Figure 8.2. Experimental setup of a transformer. (*L: Lamp*)

2. Turn off the lamps connected to the secondary coil. Observe whether the lamps in the primary coil are on or not.
3. Switch on the first lamp connected parallel to the secondary coil and record $I_1, V_1, I_2,$ and V_2 values in Table 8.1.
4. Use the data in Table 8.1 to find the powers P_1 and P_2 and record them in Table 8.1.
5. Use Eq. 8.3 to calculate the efficiency and record it in Table 8.1.
6. Switch on the second lamp on the secondary coil and repeat the steps 3, 4, and 5.
7. Switch on all of the lamps on the secondary coil and repeat the steps 3, 4, and 5.
8. Interpret the efficiencies that you found for each case.

EXPERIMENTAL DATA:

Table 8.1							
Number of Lamps	I_1 (A)	V_1 (V)	I_2 (A)	V_2 (V)	P_1 (watt)	P_2 (watt)	Efficiency
1							
2							
3							

RESONANCE in WIRE



E9

RESONANCE in WIRE

E9

PURPOSE OF THE EXPERIMENT:

To examine resonance waves on an alternating-current-carrying wire that is stretched by an attached mass and placed in a magnetic field.

EQUIPMENT FOR THE EXPERIMENT:

AC Power supply (60 V, 50 Hz)

1 rail

Pulley

Mass set

Magnets

Conducting wire

Digital scale

THEORY:

If electric current passes through a wire found within a magnetic field, and if the direction of this current and the direction of the magnetic field are perpendicular to each other, then the magnitude of the electromagnetic force on the wire exerted by field is given by:

$$F = iBl. \tag{9.1}$$

Here, i represents the magnitude of the current passing through the wire, B represents the magnitude of the magnetic field and L is the length of the wire. The direction of this force is determined by the right-hand rule. According to this relation, the force changes with the magnitude of the current, the magnetic field, and the length of the wire. If alternating current is passed through a wire, then the direction of the electromagnetic force will change continuously. It will start executing vibrational motion due to the effect of this force. The wire will vibrate transversely (up and down).

When a stable wave is formed in the wire, the frequency f of a vibrating wire is given by

$$f = \frac{n}{2L}\sqrt{\frac{F}{\mu}} \tag{9.2}$$

where L is the length of the wire, F is the stretching force, μ is the linear mass density, and n is the number of half waves. If $n = 1$, then the vibration frequency of the wire is called as fundamental frequency (see Figure 9.1 (a)).

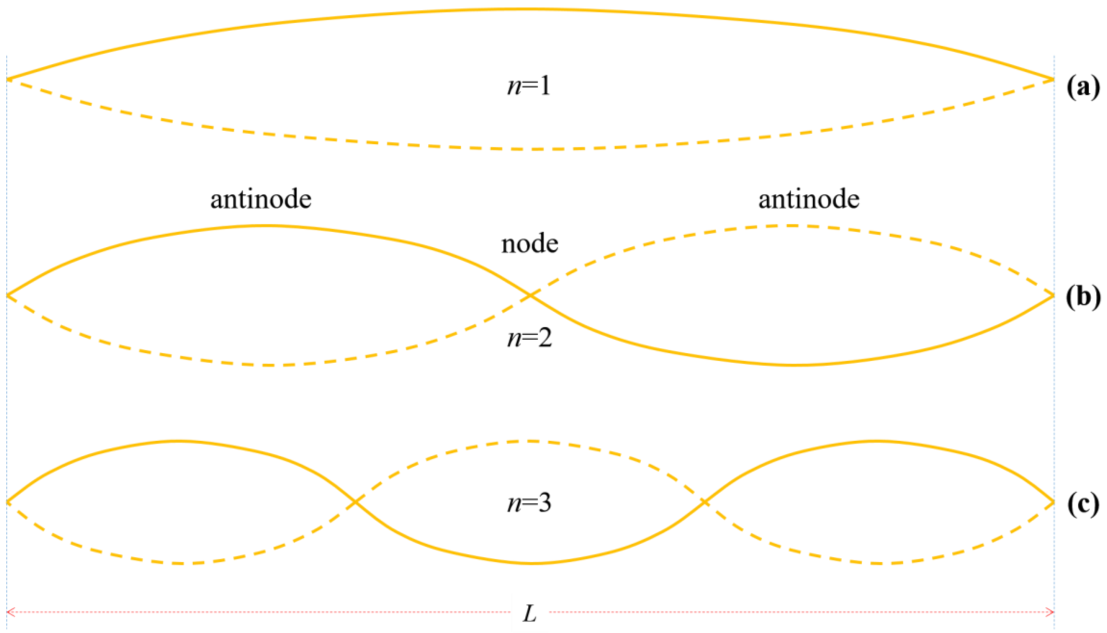


Figure 9.1. Resonance waves for $n = 1$, $n = 2$, $n = 3$.

If the frequency of the vibration formed on the wire due to electromagnetic force equals to the natural vibrational frequency of the wire, then a resonance occurs and in this case, the wire vibrates in its largest amplitude. When a resonance is obtained by changing the force to stretch the wire, the frequency of the alternating current may be estimated by calculating the force on the wire.

PROCEDURE:

1. Set up the circuit given in Figure 9.2.

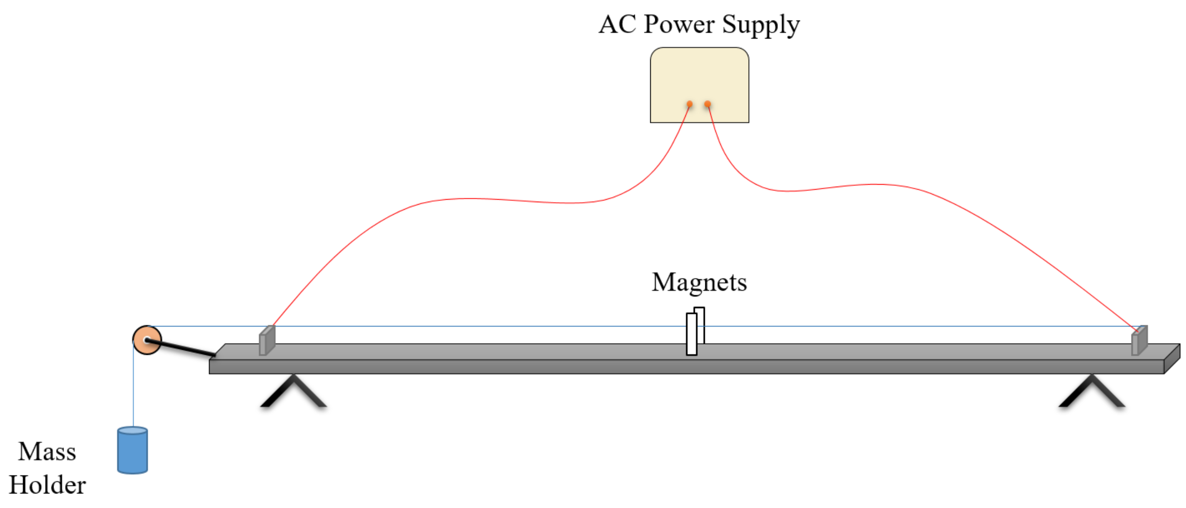


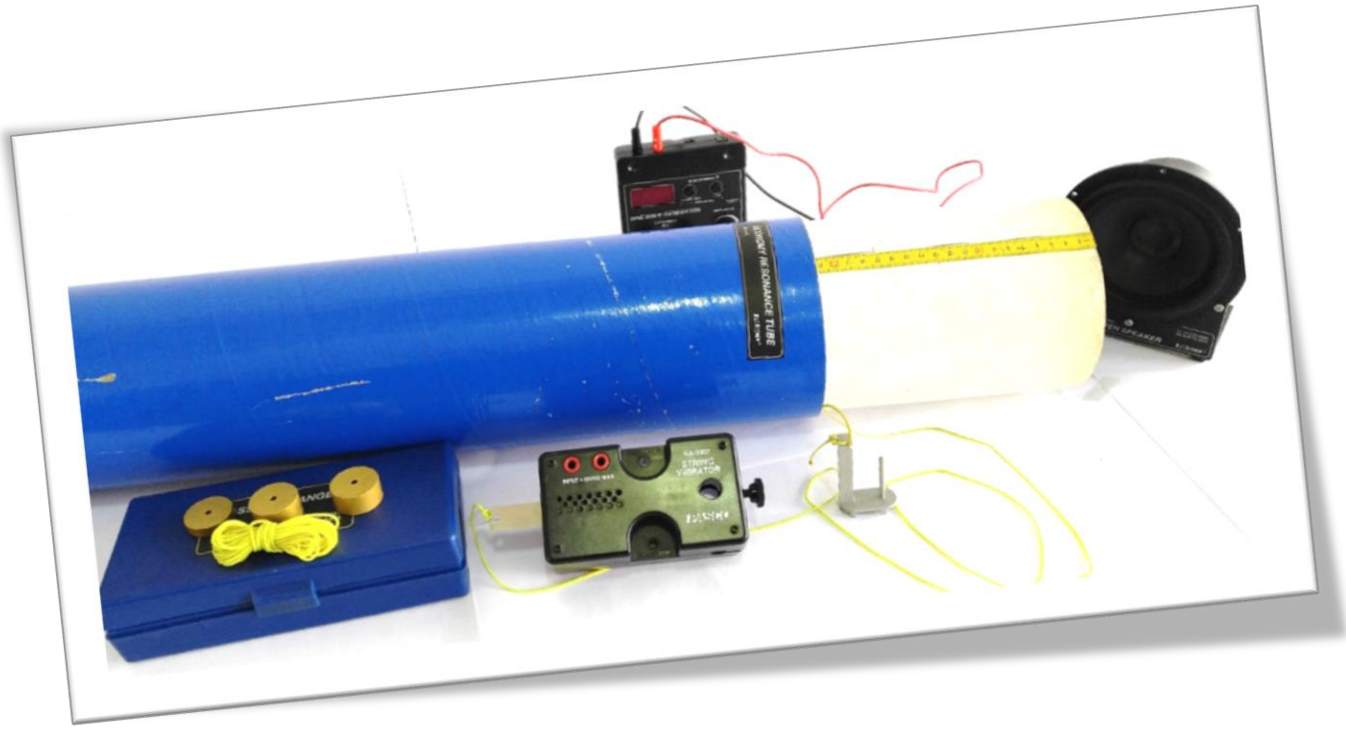
Figure 9.2. Experimental setup for resonance in wire.

2. Weigh the 5-m long conducting wire (L_{wire}) found in the experimental set using a digital scale and record m_{wire} in Table 9.1.
3. Use the equation $\mu_{wire} = \dfrac{m_{wire}}{L_{wire}}$ to calculate the linear mass density of the conducting wire and record it in Table 9.1.
4. Set the distance L between the points of supports to 1.9 m, i.e., the length of the wire section that will vibrate.
5. Make sure that the magnet is exactly at the middle of the length L and then turn on the power supply to apply alternating current to the circuit.
6. Attach different masses on the mass holder and determine the mass m that will vibrate the wire with a maximum amplitude for $n = 2$. Calculate this mass using $m = m_{holder} + m_{mass}$ and record it in Table 9.1. Note that the mass holder is 20 g.
7. Calculate the magnitude of the force F to stretch the wire using the equation $F = mg$ and record it in Table 9.1.
8. Calculate the frequency of the current passing through the wire using Eq. 9.2 and record it in Table 9.1.
9. Repeat the same procedure for $n = 3$ and interpret your results.
10. Use the average frequency f_{avg} in Table 9.1 to calculate the total mass m' that is required to be attached to the end of the wire in order to obtain $n = 1$ situation. Interpret your results.

EXPERIMENTAL DATA:

TABLE 9.1								
n	m_{wire} (kg)	L_{wire} (m)	μ_{wire} (kg/m)	L (m)	m (kg)	F (N)	f (Hz)	f_{avg} (Hz)
2		5		1.9				
3		5		1.9				

RESONANCE TUBE and STANDING WAVES



E10

RESONANCE TUBE and STANDING WAVES

E 10

PURPOSE OF THE EXPERIMENT:

To use resonance phenomenon to calculate the velocity of sound propagating in air and the density of a string.

EQUIPMENT FOR THE EXPERIMENT:

Wave generator

Mass set and hanger

String

Ruler

Roller

Speaker

Resonance tube

Connection cables

THEORY:

Resonance phenomenon occurs in a mechanical system excited by a force when the excitation frequency is the same as the natural frequency of the system. In this case, the vibration amplitude of the system tends to increase.

One open-end and one closed-end resonance tube always has a node at the closed-end and an antinode at the open-end. A node describes the minimum value of air velocity (zero) and an antinode describes the maximum value of air velocity. If the tube generates a stable resonance, it will resemble the pattern shown in Figure 10.1 where the curved lines represent the velocity profile along the tube.

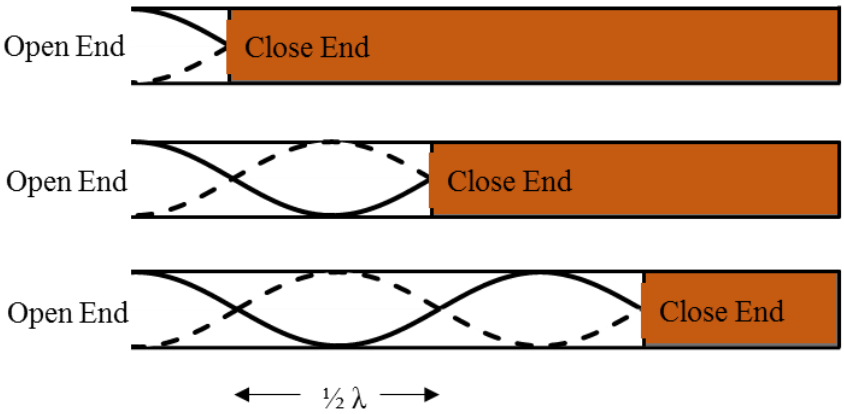


Figure 10.1. Nodes and antinodes along a resonance tube.

As the active length of the tube is increased, the sound becomes loud at each successive node and quiet at the antinodes. Note that the distance between the nodes is ½ λ.

For all types of waves, the frequency f and the wavelength λ are related to the speed of the wave v as

$$v = \lambda f. \tag{10.1}$$

Rate of sound related with temperature is theoretically given by

$$v = (331 + 0.6T) \text{ m/s} \tag{10.2}$$

where T is the temperature in centigrade degree. Operation principle of the speaker is based on electromagnetism. A magnet and a roller in the speaker interact magnetically, the diaphragm takes an action. Vibration of the diaphragm per unit time in the tube equals the wave frequency (Figure 10.2). This is a very good example for transforming electrical energy into sonic energy.

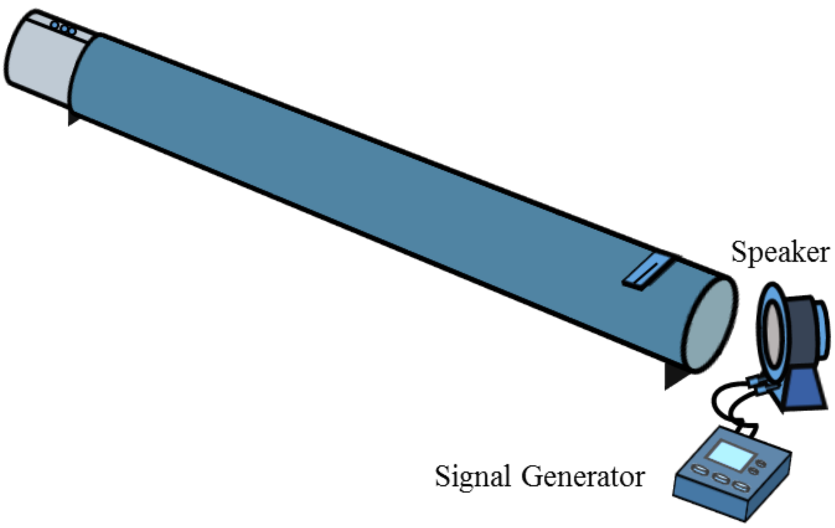


Figure 10.2. Experimental setup for resonance tube.

The nodes-antinodes in sound waves can be also observed in standing waves on a string. They are called as standing waves. A wave (sine wave) generator vibrates a stretched string by creating a standing wave pattern on it. A stretched string has many natural vibrational modes (see Figure 10.3). If the string is fixed at both ends, then there must be nodes on both ends (no amplitude) and there must be at least one antinode (maximum amplitude) along the string. It can vibrate as a single piece; in this case the string length L is equal to half of the wavelength $L = \lambda/2$. There can be nodes in the middle point and at both ends, in this case the string length is equal to the wavelength ($\lambda = L$).

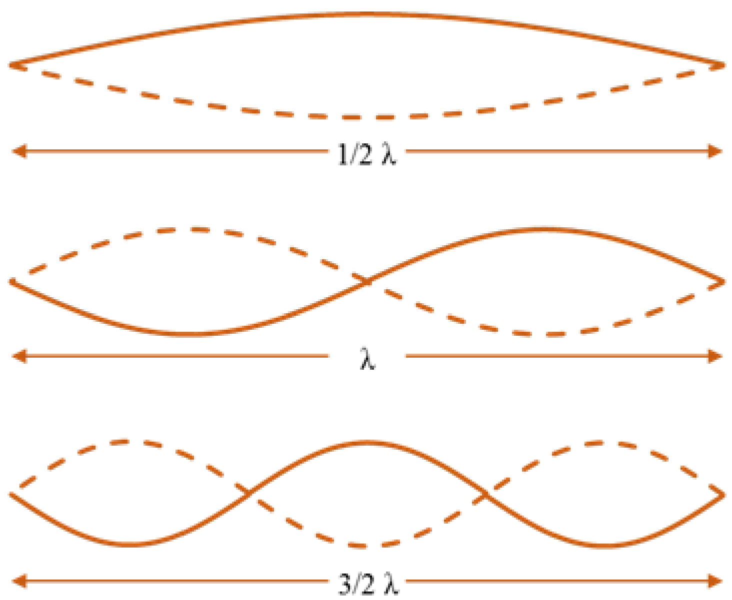


Figure 10.3. Modes of a stretched string.

If a stretched string vibrates at a random frequency, a certain mode may not be seen as many modes will be mixed with each other. However, if vibration frequency, tension, and length are well adjusted, a certain vibration mode will have a higher amplitude than the other modes.

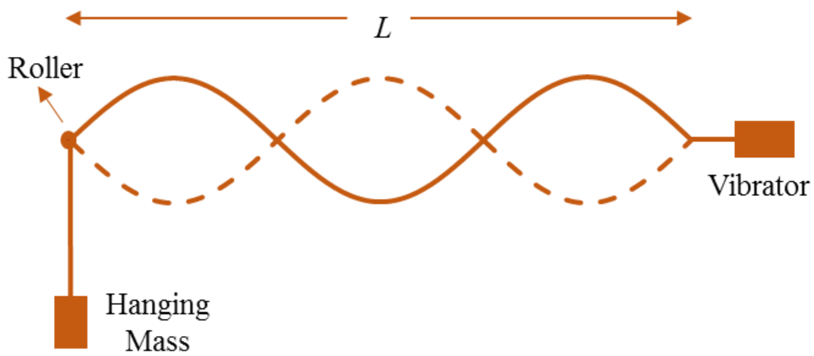


Figure 10.4. Vibrating string with three antinodes.

The velocity of a wave with a wavelength λ and frequency f is given by Eq. 10.1. Furthermore, the velocity of the wave on the string can be expressed as

$$v = \sqrt{\frac{F}{\mu}} \tag{10.3}$$

where μ is the linear mass density ($\mu = m/L$). The tension F is equal to the weight mg of the hanging mass m. Combining Eqs. 10.1 and 10.3, the frequency can be expressed as

$$f^2 = \frac{g}{\mu\lambda^2} m. \tag{10.4}$$

PROCEDURE:

A. Resonance Tube

A1. Connect the sine wave generator to the speaker. Place the resonance tube horizontally with the speaker near the closed end. Place the speaker at a 45^o angle to the end of the tube, not pointed directly into it. The inner tube can slide into the blue tube, so do not try to move the blue tube.

A2. The speaker is connected to the closed end of the resonance tube. You will slide the inner tube outside the blue tube from the other end of the resonance tube.

A3. Set the wave generator for 300 Hz and the amplitude on a reasonable level. Slide the inner white tube outside increasing the tube length. The loudness of the sound will increase as you approach resonance. Move the tube in and out to pinpoint the position that gives the loudness tone. Read this position from the ruler on the tube and record it in Table 10.1.

A4. Continue to slide the tube outside and determine all the points that cause a resonance. Each of these positions represents a node in the standing wave pattern. The first point is called as 1st node and the others as 2nd node, 3rd node …, respectively. Record these positions in Table 10.1.

A5. Calculate the distance between the nodes. Use this distance to calculate the wavelength λ of the sound wave and record it in Table 10.1.

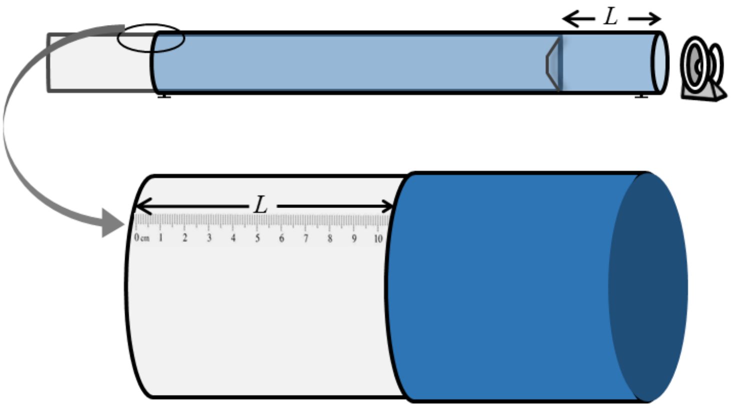


Figure 10.5. Reading of the positions on the resonance tube.

A6. Use the frequency of the sine wave generator and the wavelength λ to calculate the speed of the sound wave v in air. Record this speed in Table 10.1.

A7. Set the sine wave generator for 400 Hz and repeat the steps 3, 4, and 5.

A8. Use Eq. 10.2 to calculate the speed of sound (v_{the}) in air theoretically and record this speed in Table 10.1.

A9. Compare your experimental and theoretical values and comment on them.

B. Standing Waves

B1. Measure the length L of the string between the middle point of the roller and vibrator, then record it in Table 10.2.

B2. Hang a 50-g mass up on the mass hanger and record the total mass m including the mass of the hanger (5 g) in Table 10.2.

B3. Start the wave generator with the frequency 0 Hz and slowly increase it until you get four antinodes with maximum amplitudes and nodes fully damped (see Figure 10.6). Record this frequency f in Table 10.2. You should get four antinodes in all of the following steps.

B4. Add masses in increments of 50 g and adjust the frequency so that the same number of antinodes is obtained. Repeat the same procedure up to 250 g.

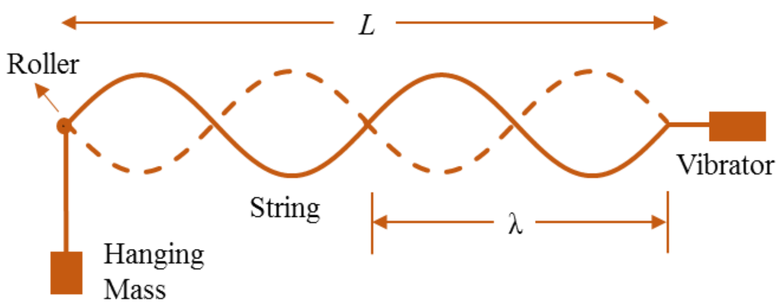


Figure 10.6. Vibration pattern to be obtained.

B5. Draw the graph of $f^2 = f(m)$. Use the slope of this graph and Eq. 10.4 to calculate the linear mass density μ. Here, note that $L = 2\lambda$ as shown in Figure 10.6. Record this density in Table 10.2.

B6. Measure the mass of the 5-m long string and record it in Table 10.3. Use its length L_{string} and its mass m_{string} to calculate linear mass density μ_{the} and record it in Table 10.3.

B7. Compare your experimental and theoretical linear mass densities.

B8. Common electrical power transmission network has an alternating current. How could you obtain the frequency of this alternating current with a similar experiment? Explain.

EXPERIMENTAL DATA:

TABLE 10.1							
f (Hz)	1st resonance point (cm)	2nd resonance point (cm)	3rd resonance point (cm)	λ (m)	v (m/s)	T (°C)	v_{the} (m/s)
300							
400							

TABLE 10.2		
L = ……………… m		
m (kg)	f (Hz)	f^2 (Hz^2)
0.055		
0.105		
0.155		
0.205		
0.255		
μ = ……………….. kg/m		

TABLE 10.3
L_{string} = ……………… m
m_{string} = ……………… kg
μ_{the} =……………. kg/m

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